AD/A-001 978

A RESPONSE SURFACE FOR THE COMPLEX MODULUS OF COMPOSITE MATERIALS

Charles E. Arthur, et al

Virginia Polytechnic Institute and State University

Prepared for:

Air Force Materials Laboratory

30 October 1974

DISTRIBUTED BY:

NTIS
National Technical Information Service
U. S. DEPARTMENT OF COMMERCE

NOTICE

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

Copies of this report should not be returned unless return is required by security considerations, contractual obligations, or notice on a specific document.

UNCLASSIFIED

Security Classification

AD/A-001 978

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Virginia Polytechnic Institute & State University	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP
3. REPORT TITLE A RESPONSE SURFACE FOR THE COMPLEX MODULUS OF COMPOSITE MATERIALS	
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Technical Report, July 1972 - April, 1974	
5. AUTHOR(S) (First name, middle initial, last name) CHARLES E. ARTHUR, AGNES S. HELLER AND ASHOK B. THAKKER	
6. REPORT DATE May 197	7a. TOTAL NO. OF PAGES 68 7b. NO. OF REFS 12
8a. CONTRACT OR GRANT NO. F33615-72-C-2111 b. PROJECT NO. 7340 c. Task No. 734003 d.	9a. ORIGINATOR'S REPORT NUMBER(S) 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) AFML-TR-74-185
10. DISTRIBUTION STATEMENT Approved for public release; distribution unlimited.	
11. SUPPLEMENTARY NOTES Reproduced by NATIONAL TECHNICAL INFORMATION SERVICE US Department of Commerce Springfield, VA. 22151	12. SPONSORING MILITARY ACTIVITY Air Force Materials Laboratory Wright-Patterson Air Force Base, Ohio 45433

13. ABSTRACT

The complex modulus of boron/epoxy and graphite/epoxy laminates has been measured in forced vibration tests at frequencies ranging from 20 to 17,000 Hz and temperatures varied between -50° and +300°F.

The data was analyzed using response surface methodology. Based on the response surface time-temperature shift parameters, master curves, and probability relations have been developed.

DD FORM 1 NOV 65 1473

UNCLASSIFIED

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Composite Materials						
Laminated Composites						
Complex Modulus						
Response Surface						
Time-Temperature Effects						
Vibration Tests						

AFML-TR-74-185

A RESPONSE SURFACE FOR THE COMPLEX MODULUS OF COMPOSITE MATERIALS

COLLEGE OF ENGINEERING
VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY
BLACKSBURG, VIRGINIA 24061

Technical Report AFML-TR-74-185

October 30, 1974

Approved for release; distribution unlimited.

Air Force Materials Laboratory
Air Force System Command
Wright Patterson Air Force Base, Ohio

ib

FOREWORD

The research and development reported herein was conducted under Air Force Contract F33615-72-C-2111 at Virginia Polytechnic Institute and State University. The work was initiated under Project 7340, "Nonmetallic and Composite Materials", Task 734003, "Structural Plastics and Composites". The Air Force Project Engineer directing the program was Dr. J. Whitney (AFML/MBM) of the Mechanics and Surface Interactions Branch, Nonmetallic Materials Division, Air Force Materials Laboratory at Wright-Patterson Air Force Base, Ohio. Dr. R. A. Heller was Principal Investigator at Virginia Polytechnic Institute and State University.

The work covered in this report was performed by C. E. Arthur, A. S. Heller, and A. B. Thakker of Virginia Polytechnic Institute and State University.

The report covers part of the work conducted between 1 Jul 1972 and 30 Apr 1974.

The report was submitted by the authors in May 1974.

This technical report has been reviewed and is approved for publication.

J. M. Whitney

J. M. WHITNEY
Project Engineer

FOR THE COMMANDER

S. W. TSAI, Chief
Mechanics & Surface Interactions Branch
Nonmetallic Materials Division

ABSTRACT

The complex modulus of boron/epoxy and graphite/epoxy laminates has been measured in forced vibration tests at frequencies ranging from 20 to 17,000 Hz and temperatures varied between -50° and +300°F.

The data was analyzed using response surface methodology. Based on the response surface time-temperature shift parameters, master curves, and probability relations have been developed.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (continued)

LIST OF TABLES

SECTION I

INTRODUCTION

The significance of the role of advanced composite materials in many engineering applications is increasing. Environmental effects on the material properties of composites is an important aspect of design considerations.

To determine the long term influence of the individual contributions of time, temperature, and humidity on composite materials would require extensive numbers of specimens and tests. In order to isolate significant variables experiments have been designed for maximum utilization of specimens.

Due to wide variation in the information obtained from experimentation a statistical analysis of the data was conducted. Multiple regression techniques were employed and the significance of the individual variables was tested.

This experimental program resulted in the development of response surfaces for the complex moduli of composite materials.

SECTION II

REVIEW OF PERTINENT LITERATURE

Environmental effects on the mechanical properties of advanced composites have received only limited theoretical analyses. Most of the work done in this area has been experimental in nature because of the complexity of the problem. The choice of fiber, matrix, and layup of fiber reinforced, laminated composites are important in the consideration of environmental effects.

Kaminski, Lemmon, and McKague [Reference 1] discuss a regression analysis method for establishing temperature allowables. This approach places statistical significance on a temperature retention curve. The statistical model suggested by them is

$$y = b_0 + b_1 T + b_2 T^2 + e$$

where y is the response (stress or strain), T is the test temperature, and e is random error. The error term, e, accounts for the variation in observed results at a constant temperature and is assumed to be normally distributed with mean zero and variance σ^2. The variance of e is assumed

to be the same for all temperatures. The constants b_0, b_1, and b_2 are regression coefficients and are estimated from least squares techniques.

Reference 2 describes an experimental approach for finding humidity and thermal effects on graphite/epoxy composites. These tests involved hygrothermal exposures (combinations of constant temperature and constant humidity) and dynamic exposures (changing temperature and/or humidity) of the specimens. The specimen lay-up and thickness is varied in this approach. Tests to determine water desorption as well as absorption behavior were conducted. The effects of moisture on certain properties were determined by mechanical tests. The effects of increasing the moisture content is seen to increase the creep of the material. Also it is seen that at elevated temperatures there is a loss of flexural and shear strength with increased moisture content.

Browning and Whitney [Reference 3] find that the effects of absorbed moisture on the elevated temperature mechanical properties of fiber-reinforced laminates is highly dependent on the lay-up of the material and the type of loading. For example, a quasi-isotropic boron epoxy laminate when tested in tension at 350 F after exposure to high humidity has approximately the same tensile properties as it did at 350 F before moisture was absorbed. The same material, with a uni-directional lay-up and tested in flexure, shows a 50% reduction in its 350°F flexure strength, although the same amount of moisture was absorbed as in the first specimen.

It is also found in Reference 3 that in the epoxy laminate systems water behaves as a plasticizing agent that disrupts the strong hydrogen bonds. The reversibility of this water absorption process is shown by the change of properties from "dry" to "wet" specimens. The "wet" specimens, after being dried, exhibit the same properties as they did before exposure. Fiber controlled composites have much less dependence on moisture absorption than matrix controlled materials. However, both exhibit this reversibility.

Pritchard and Taneja [Reference 4] state that the rate at which hot water degrades a glass fiber reinforced resin is accelerated by stress. The resin, fiber, and coupling agent are all susceptable to hydrolysis. Swelling and crack formation have been observed in low molecular weight constituents. These phenomena occur more rapidly when the laminate is stressed. Specimens which were exposed to water on one side only were used to determine the rate at which water permeates into them. A dependence upon the molecular structure of the resin, the void volume and the mobility is seen. The rate of degradation is expected to have a relationship upon the permeation rate of water in the material.

Reference 5 states that the effect of moisture is generally to reduce the strength and ultimate strain of a composite. However, the

stress-strain characteristics and the initial modulus are not greatly altered by exposure to humidity. No significant change in strength or modulus was seen in cross-ply laminates.

Halpin [Reference 6] states that although the range of interest for the linear viscoelastic behavior of polymers can cover a large number of decades in time or frequency the range of any given experimental instrument is limited. In order to obtain values of the response function over a wide range of frequency or time, a suitable procedure is to change the effective time or frequency scale by changing the ambient conditions, such as temperature.

It is found in many cases that observations of the material response taken over a range of frequency or time at one temperature will result in good superposition upon observations taken at a different temperature if a simple translation along the log time axis is made. This means that a change in temperature is equivalent to a change in the time scale. A master curve can be developed for a reference temperature from which all other temperature curves can be developed by a time shift. This relationship between the temperature and time scale can be represented by a shift factor a_T. This shift factor is the ratio of the time scale at an arbitrary temperature to the time scale at a reference temperature, T_r. A function of the reference temperature and the arbitrary temperature can be used to define a_T [Reference 6].

There is a similar effect of water absorption upon the time scale which can be characterized by a water concentration shift factor a_c. A master curve can also be developed at a reference humidity. A simultaneous change in temperature and water concentration could be approximated by a reduced time, $t/a_T a_c$ [Reference 6].

Acceleration of testing can be obtained by using these time shift factors. The effect of increasing temperature and water concentration is to decrease the time required to carry out experimentation.

In addition to time shifting there are vertical shifts in the storage moduli predicted by the kinetic theory of rubber elasticity. This theory indicates that for ideal rubber-like networks the storage modulus should be inversely proportional to the product of absolute temperature and density. The response is therefore shifted by a factor

$$\frac{E'}{E_r'} = \frac{\rho_r T_r}{\rho T}$$

where ρ and T are the density and absolute temperature that correspond to the response E' and ρ_r is the density taken at the reference temperature T_r. The response at the reference temperature is E'_r [Reference 6].

Composite materials consisting of elastic fibers and a viscoelastic matrix behave in a more complex manner than do thermo-rheologically simple, linear viscoelastic materials. It is, however, possible to develop time-temperature superposition methods for such materials based mostly on experimental evidence, though the theoretical explanation of some of the nonlinear characteristics is not yet available.

The experiments and the analysis of the data presented here show a methodology for the determination of shift parameters and indicates the accelerating effects of various environmental variables.

SECTION III

SPECIMENS

The specimens chosen for the experiments were fiber controlled laminates with epoxy matrices. One metallic fiber and one non-metallic fiber was used. The Brunswick Corporation of Marion, Virginia fabricated the specimens.

The metallic fiber, boron was purchased from Avco Corp. as 55-05 boron tape with specific gravity 2.012. This tape was layed up as follows: 0°, $\pm$45°, 0°, 0°, $\mp$45°, 0°, with each angle measured from the longitudinal axis of the specimen. These eight ply specimens have a thickness varying from .040 to .045 in. The material was fabricated in panels approximately 12 to 15 in. wide and 15 to 21 in. long.

The second material was fabricated from Hercules X3501A-S graphite tape in an eight ply laminate identical to the boron epoxy lay-up. The panels were approximately 12 in. wide and 16 to 21 in. long. The specific gravity of the graphite specimens is 1.476.

Test specimens were routed from the panels using a slotted router coated with 60/80 diamond grit. This insured minimum fiber breakout at the ends. The ends were kept perpendicular and the edges parallel to the fiber direction. The specimen width was .75 in. in four different lengths, 5, 10, 15, and 20 in. [Reference 7].

SECTION IV

VIBRATION TESTS

Advantages of Vibration Testing

Forced vibration testing as a means for obtaining experimental data has several desirable features. Since the test itself is non-destructive many observations can be taken from a single specimen. This drastically

reduces the need for a large number of specimens. The ease with which observations are taken makes the collection of a large amount of data possible. This was essential for the statistical analysis used.

Measurement of the Complex Modulus

The complex modulus is determined from a forced oscillation experiment in which the lag angle, δ, between the imposed sinusoidal strain

$$\varepsilon = \varepsilon_0 \exp(j\omega t) \tag{1}$$

and the resulting sinusoidal stress

$$\sigma = E^*\varepsilon = |E^*|\, \varepsilon_0 \exp j\,(\omega t-\delta) \tag{2}$$

is measured. In equations (1) and (2) ε_0 is the strain amplitude, ω is the circular frequency, j is $\sqrt{-1}$, t is time, and

$$E^* = E'(1+j \tan \delta) \tag{3}$$

is the complex modulus. The storage modulus, E', is the real part and the loss modulus, E'', is the imaginary part of the complex modulus. When the lag angle is small,

$$E'' = Im(E^*) = E'\tan \delta = E'\,\delta \tag{4}$$

Forced vibration experiments were performed using transverse and axial excitation on both materials. For low frequencies (20-5000 Hz) specimens were vibrated in a double cantilever bending configuration by clamping them at midspan to an accelerometer fastened to the moving element of an electromagnetic shaker. For higher frequencies (4,000-17,000 Hz) the specimens were vibrated axially (vertically) by clamping one end of each specimen in the accelerometer as shown in Figures 1 and 2.

The experiments were carried out in a temperature controlled cabinet with six temperature levels ranging from -50°F to +300°F. The excitation frequency was varied continuously by a sweep oscillator and the acceleration of the moving element of the shaker was kept constant by an electronic servo/monitor in a feedback loop (Fig. 3).

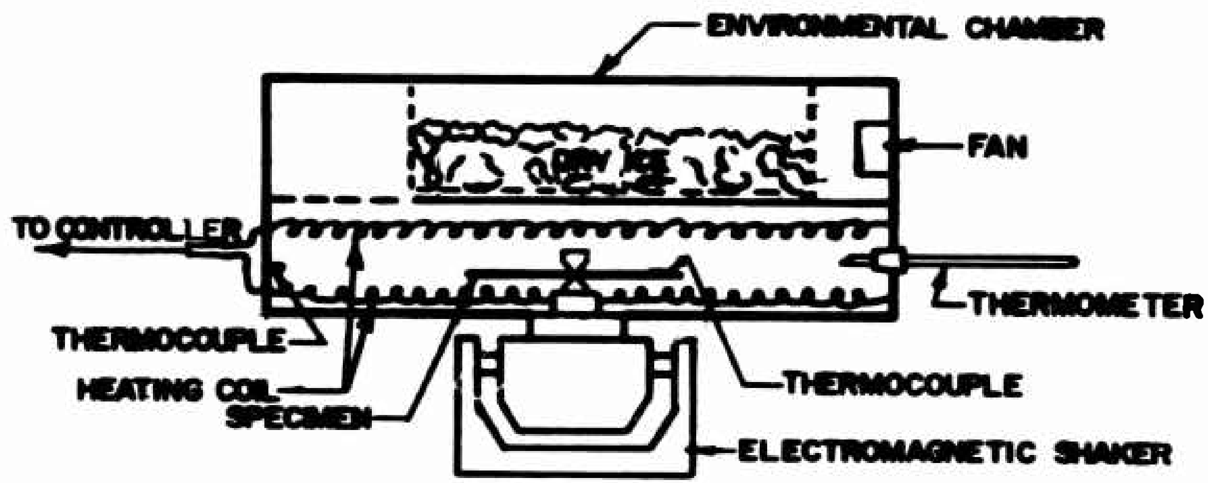

Figure 1. Test Configuration for Transverse Vibration

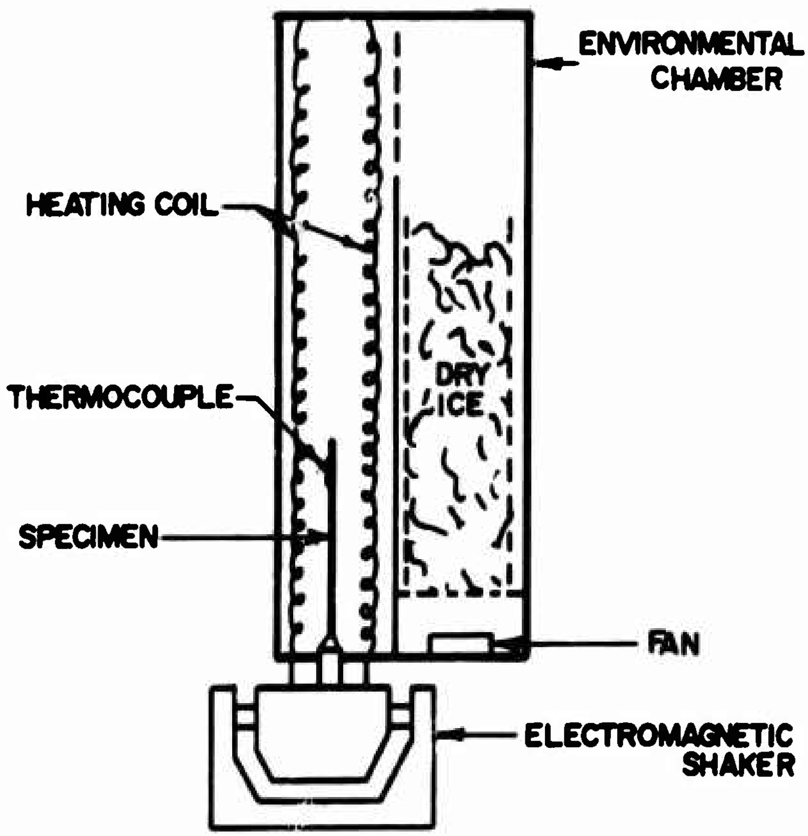

Figure 2. Test Configuration for Axial Vibration

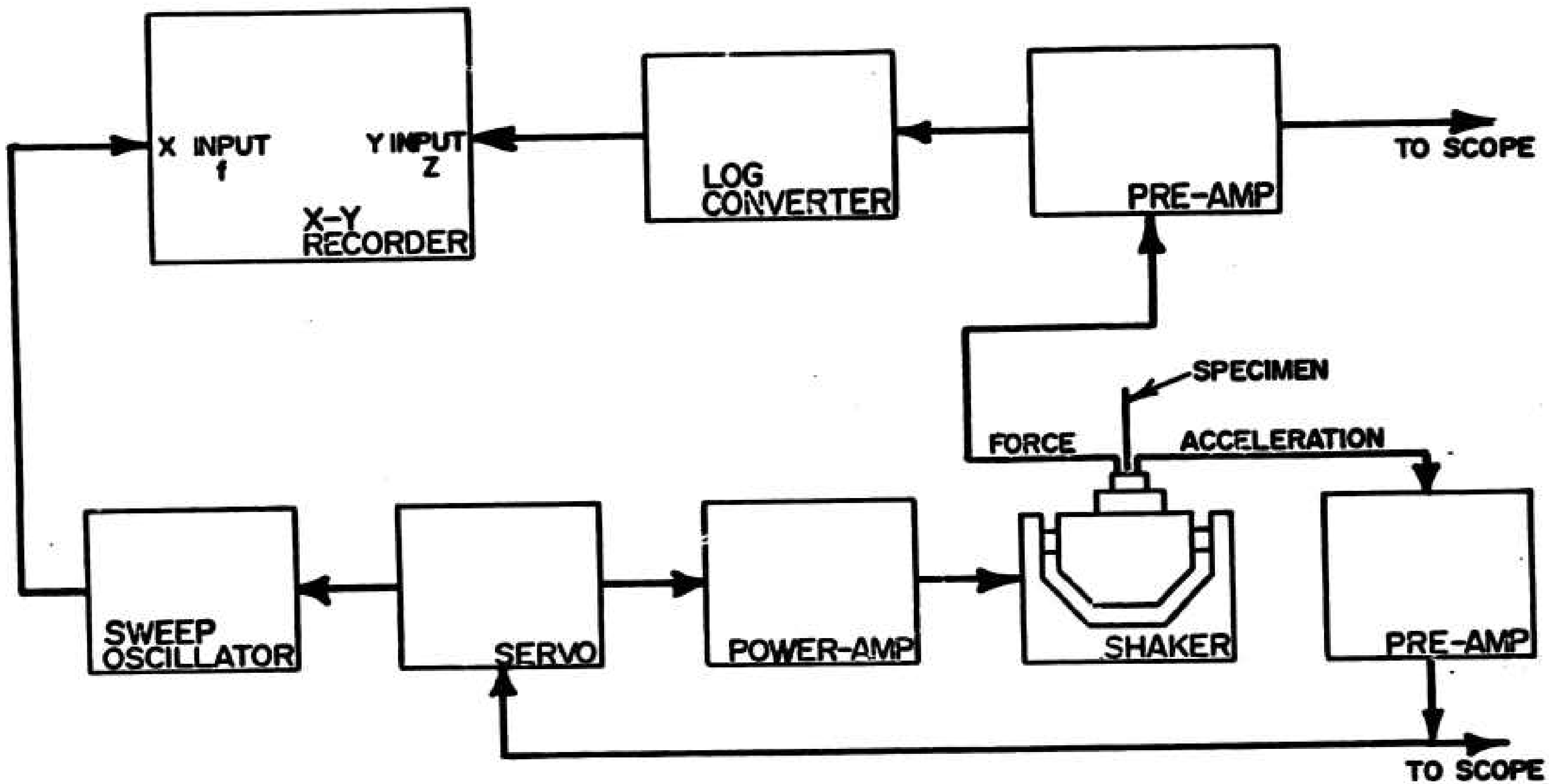

Figure 3. Schematic Diagram of Vibration Testing System.

An XY plotter recorded a force/acceleration versus frequency curve for each observation. These curves (Figure 4) reached a maximum value at the anti-resonant frequency and a minimum value at the resonant frequency. The anti-resonant frequency was used to determine the modulus and damping characteristics of the specimen. The effect of the mass of the accelerometer and specimen holder are not present at anti-resonance. If the resonance had been used additional electronic equipment would have been necessary to provide for mass cancellation (Figure 5). For transverse vibration the lowest three anti-resonant peaks were observed. In the axial tests only the first vibration mode was observed because the frequency response of the test system was not high enough to monitor additional modes. (The upper limit of the system was approximately 20 kHz.)

The storage modulus and lag angle (damping ratio) were calculated with the aid of isotropic beam and bar theories. Since the ratios of length to thickness ranged from 455:1 to 110:1 the effects of shear were negligible and Euler's bending theory was used.

For a homogeneous isotropic bar in axial excitation the normalized driving point impedence, Z, is given by

$$\frac{Z}{J\omega M} = \frac{F_1/a_1}{M} = \frac{1}{n^*\ell} \tan n^*\ell + \gamma \qquad (5)$$

where F_1 is the driving force, a_1 is the acceleration of the transducer of mass m_1, $M = \rho A\ell$ is the mass of the bar with ρ the mass density, A the cross-sectional area and ℓ the length; $n^* = \omega \sqrt{\rho/E^*}$ and $\gamma = m_1/M$.

The relation between the storage modulus and the frequency is given by

$$C^2 = \frac{E'}{\rho} \qquad (6)$$

where C, the wave speed is

$$C = f_n\lambda_n \qquad (7)$$

Here f_n is the frequency in Hertz at an anti-resonance and λ_n is the wavelength for the anti-resonance.

For the fixed-free boundary conditions used here

$$\lambda_1 = 4\ell,\ \lambda_2 = \frac{4\ell}{3},\ \lambda_3 = \frac{4\ell}{5},\ \cdots \qquad (8)$$

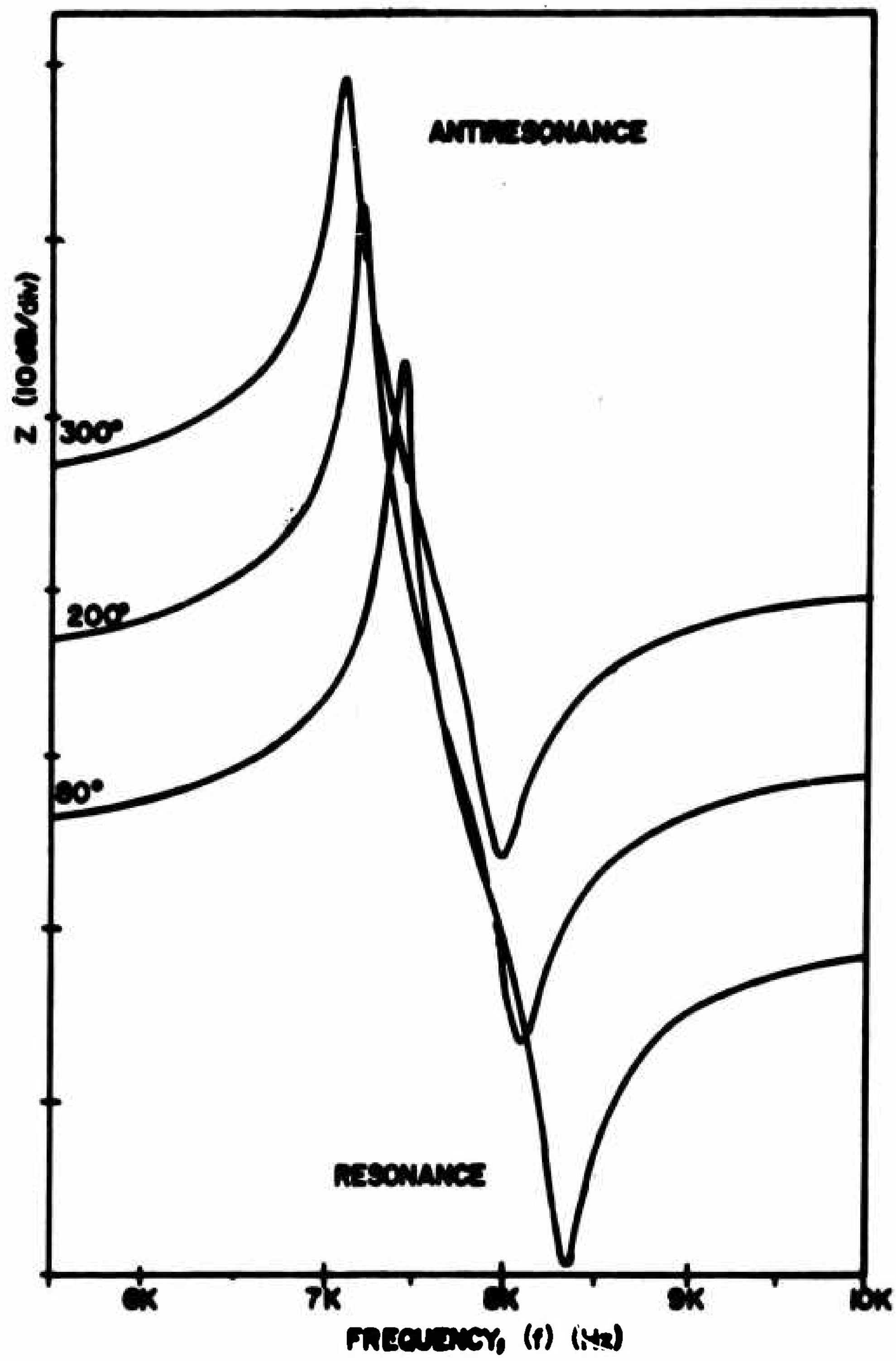

Figure 4. Typical Axial Vibration Test Results on Boron/Epoxy Specimens at Various Temperatures

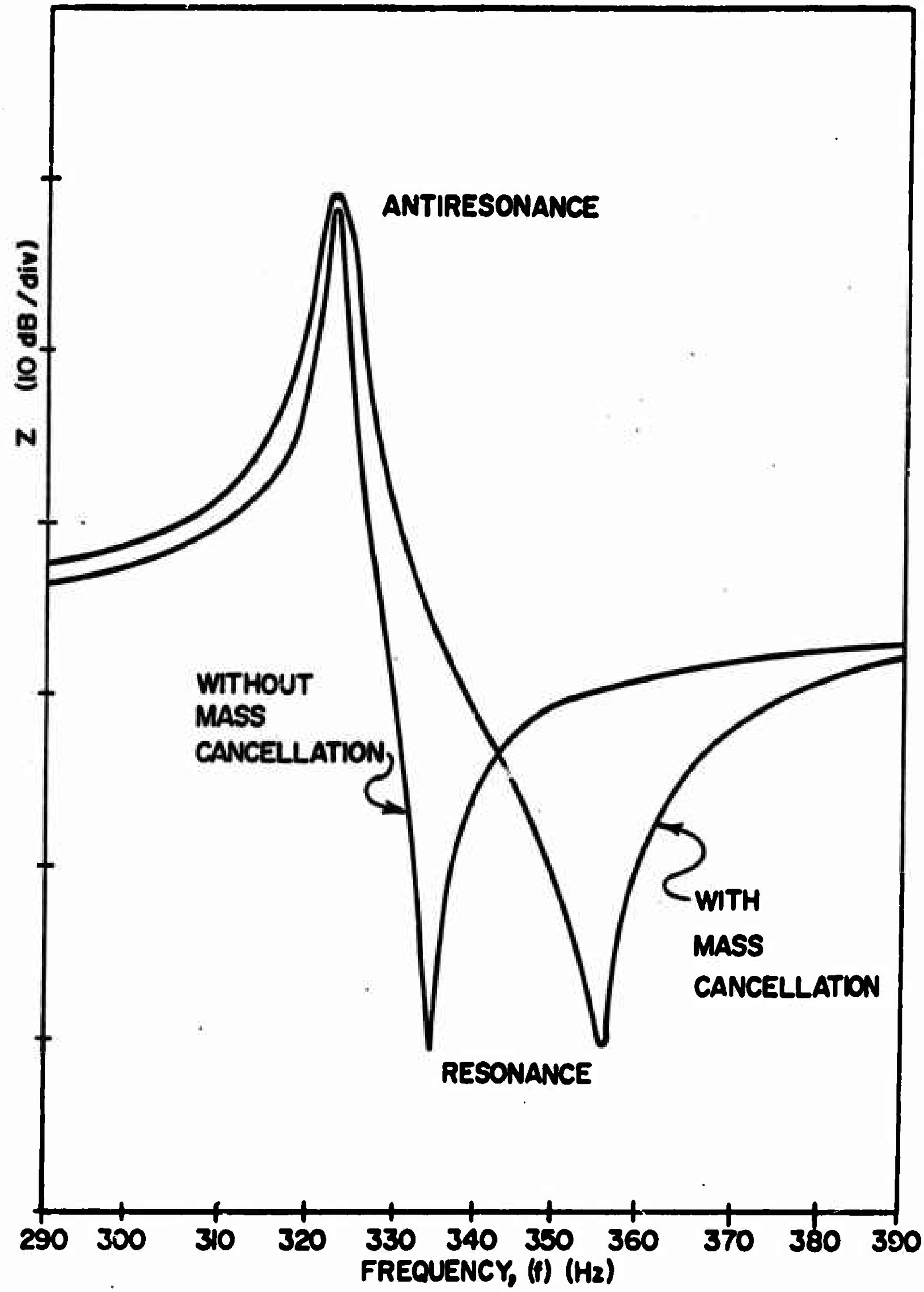

Figure Effects of Mass Cancellation on Resonance and Antiresonance Peaks.

Therefore it follows that at first anti-resonance

$$E' = 16\ell^2\rho f_1^{\,2} \tag{9}$$

At anti-resonance Z reaches a maximum.

For small δ, at an anti-resonance, it can be shown that

$$\delta = \frac{\omega_2' - \omega_1'}{\omega_n} = \frac{f_2' - f_1'}{f_n} \tag{10}$$

where f_n is the n^{th} anti-resonant frequency and f_2' and f_1' are the half power frequencies as shown in Figure 6. At the half power points the impedence is equal to .707 times its peak value at anti-resonance. The half power points are 3 Db below the peak when plotted on a logarithmic scale. The impedence, Z, is plotted in Figure 6 resulting in a maximum at the anti-resonance frequency.

It can also be shown that the storage modulus for vibration of a double cantilever beam driven by a sinusoidal force at the midpoint is given by

$$E' = \frac{48\pi^2 f_n^{\,2}\rho}{h^2}\left[\frac{\ell}{2(na)}\right]^4 \tag{11}$$

where h is the thickness of the beam. Values of the parameter "na" are given in Snowden [Reference 8]: $na_1 = 1.8751$, $na_2 = 4.6941$, $na_3 = 7.8548$. The value of the damping ratio is again computed from equation (10).

SECTION V

DEVELOPMENT OF A RESPONSE SURFACE

Multiple Regression Procedure

The response surface problem is to find the response, y, which depends upon a set of k controllable variables, x_1, x_2, ..., x_k, that is

$$y = f(x_1, x_2, \ldots, x_k) \tag{12}$$

The form of f in equation (12) is unknown but is assumed to be a polynomial function of low order.

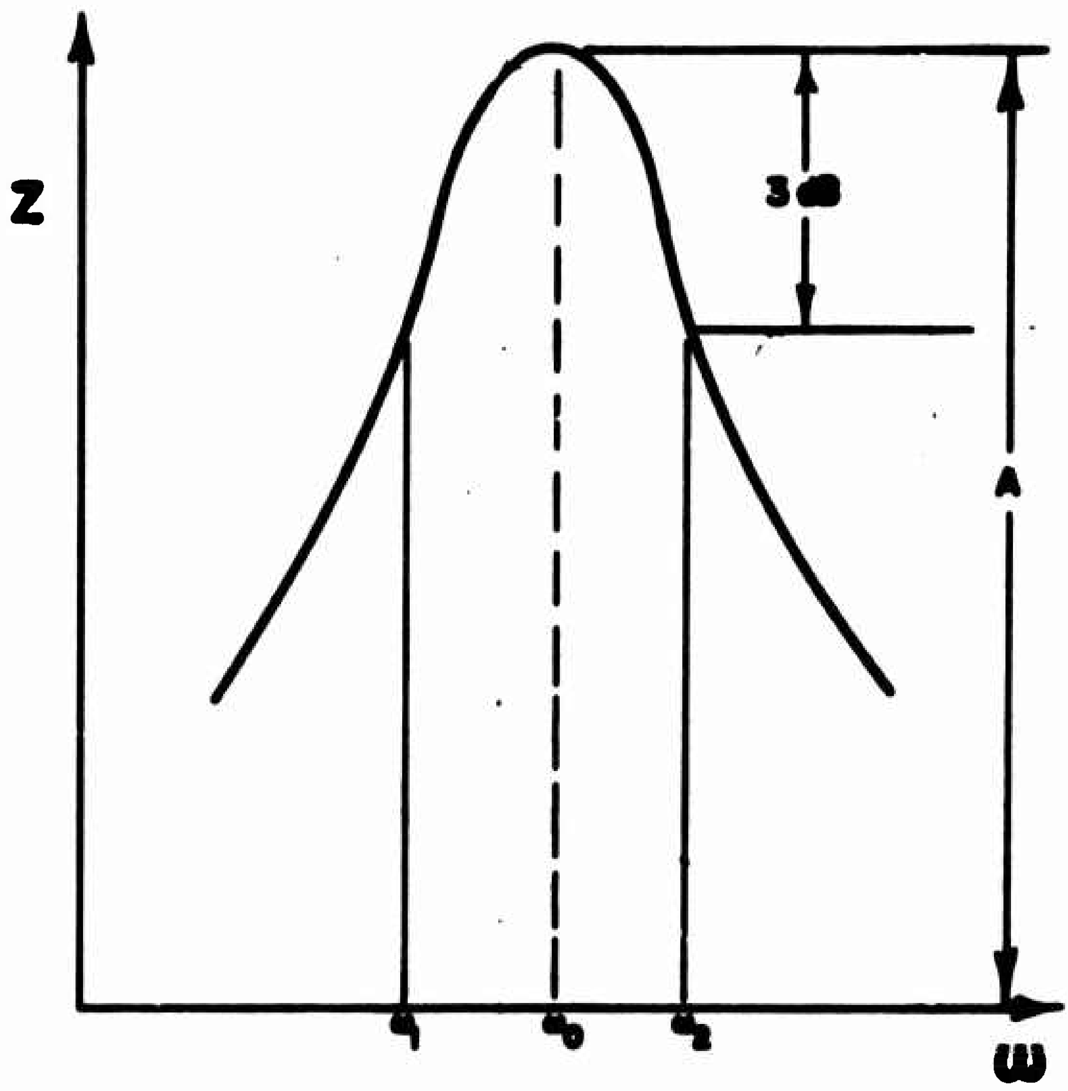

Figure 6. Measurement of Damping Ratio

If k=2 one might assume a model for y of the form

$$y = \beta_0+\beta_1 x_1+\beta_2 x_2+\beta_{11} x_1^2+\beta_{22} x_2^2+\beta_{12} x_1 x_2+\varepsilon \tag{13}$$

where β_0, β_1, ..., β_{12} are coefficients to be estimated, y is the measured response, and ε is random error.

If n experimental observations are made the data can be written in the following form

$$\begin{array}{ccc} y_1 & x_{11} & x_{21} \\ y_2 & x_{12} & x_{22} \\ \cdots & \cdots & \cdots \\ y_n & x_{1n} & x_{2n} \end{array}$$

The number of observations must be greater than the number of coefficients to be estimated. The i th observation can be written as

$$y_i = \beta_0+\beta_1 x_{1i}+\beta_2 x_{2i}+\beta_{11} x_{1i}^2+\beta_{22} x_{2i}^2+\beta_{12} x_{1i} x_{2i}+\varepsilon_i \tag{14}$$

where ε_i is a random variable. It is assumed that ε_i is independent from observation to observation and is normally distributed with variance σ^2. The model of equation (14) can be written in matrix notation as

$$\underline{y} = [X]\underline{\beta} + \underline{\varepsilon} \tag{15}$$

where

$$\underline{y} = \begin{Bmatrix} y_1 \\ y_2 \\ \cdots \\ y_n \end{Bmatrix}, \quad \underline{\varepsilon} = \begin{Bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \cdots \\ \varepsilon_n \end{Bmatrix} \tag{16}$$

$$\underline{\beta} = \begin{Bmatrix} \beta_0 \\ \beta_1 \\ \beta_2 \\ \beta_{11} \\ \beta_{22} \\ \beta_{12} \end{Bmatrix} \tag{17}$$

and

$$[X] = \begin{bmatrix} 1 & x_{11} & x_{21} & x_{11}^2 & x_{21}^2 & x_{11}x_{21} \\ 1 & x_{12} & x_{22} & x_{12}^2 & x_{22}^2 & x_{12}x_{22} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ 1 & x_{1n} & x_{2n} & x_{1n}^2 & x_{2n}^2 & x_{1n}x_{2n} \end{bmatrix} \tag{18}$$

The method of least squares is used to estimate the regression coefficients of equation (17). The least squares method uses as an estimate for $\underline{\beta}$ the vector that minimizes the sum of the squares of the errors

$$L = \sum_{i=1}^{n} \varepsilon_i^2 = \underline{\varepsilon}'\underline{\varepsilon} . \tag{19}$$

L can be written as

$$L = (\underline{y}-[X]\underline{\hat{\beta}})' (\underline{y}-[X]\underline{\hat{\beta}}) \tag{20}$$

where $\underline{\hat{\beta}}$ is the vector of estimates for $\underline{\beta}$.

Expanding the right hand side of equation (20)

$$L = \underline{y}'\underline{y}-([X]\underline{\hat{\beta}})'\underline{y}-\underline{y}'([X]\underline{\hat{\beta}})+([X]\underline{\hat{\beta}})'([X]\underline{\beta})$$

$$L = \underline{y}'\underline{y}-2\underline{\hat{\beta}}'[X]'\underline{y}+\underline{\hat{\beta}}'[X]'[X]\underline{\hat{\beta}} \tag{21}$$

To find the $\underline{\hat{\beta}}$ which minimizes L, equation (21) is differentiated.

$$\frac{\partial L}{\partial \beta} = -2[X]'\underline{y}+2[X]'[X]\hat{\underline{\beta}} \tag{22}$$

Setting the partial derivative to zero and solving for $\hat{\underline{\beta}}$, the least squares estimator is

$$\hat{\underline{\beta}} = ([X]'[X])^{-1}[X]'\underline{y} \tag{23}$$

These equations are called the "normal equations" for estimating $\underline{\beta}$.

The preceding development follows that of Myers [Reference 9].

Statistical Analysis System (SAS) computer programs were used to conduct the least squares regression [Reference 10]. Estimates were made for the regression coefficients for several polynomial models. Temperature, T, and the natural logarithm of time, t, were used as the independent variables in the models, where time is the period of oscillation at anti-resonance. Because of the assumption that the errors, ε_i, are normally distributed, the implication that the components of the complex modulus can take on negative values exists. This is due to the fact that the normal distribution extends to plus and minus infinity. This physical impossibility is resolved by using lnE' and lnE" as the dependent variables in the regression analysis.

The computer program not only estimates the regression coefficients but chooses the model that produces the maximum R^2. R^2 is the multiple correlation coefficient which is a measure of the percentage of variance in the dependent variable that has been accounted for by all of the independent variables combined [Reference 11]. Tests of significance are also conducted on the regression coefficients.

Although models up to fourth order were tried, the computer program showed that models above second order did not offer any appreciable improvement in fit. Therefore second order models were developed for the responses which include only those coefficients deemed significant by the computer program.

Response Surfaces

Using the above procedure response surfaces were developed for lnδ, lnE', and lnE" for both boron epoxy and graphite epoxy. These surfaces were of the form

$$\ln y = A + B\ln t + C\ln^2 t + DT + ET^2 + FT\ln t \tag{24}$$

where y is either δ, E', or E". The values of the coefficients are given in Tables 1 and 2. The multiple correlation coefficient, R^2, and the error standard deviation, σ, is also given for each surface in Table 1.

To aid in visualizing these surfaces contour plots are given (Figures 7, 8, 12, and 13). These plots were drawn by an XY plotter controlled by a digital computer which used the regression equations. The temperature scale is the abcissa and time (period) is the ordinate. There are plots for both the storage and loss moduli of boron epoxy and graphite epoxy.

When temperature is held constant the result is a two dimensional curve which is the intersection of a constant temperature plane and the response surface. Such constant temperature cuts were made using the experimental temperatures with the results shown for boron epoxy in Figures 9 and 10 and for graphite epoxy in Figures 14 and 15.

The regression relation, Equation 24, estimates a mean surface (mean line for constant temperature). It is possible to establish confidence bands for this mean surface. It is also possible to estimate tolerance bands for new observations.

The probability that a new observation will fall within the limits prescribed by y' is $\alpha/2\%$, where

$$y' = y \pm z_{\alpha/2}\, \sigma \,\{1 + \underline{x}([X]'[X]^{-1})\underline{x}'\}^{1/2} \tag{25}$$

In this equation y is the value of the response (lnδ, lnE', lnE") on the regression surface defined by equation (24) and

$$\underline{x} = [1, \ln t, \ln^2 t, T, T^2, T\ln t] \tag{26}$$

σ is the error standard deviation given in Table 1, $z_{\alpha/2}$ is the normal statistic corresponding to the $\alpha/2$ probability of exceedence, $\underline{x}([X]'[X])^{-1}\underline{x}'$ is a quadratic form with $\underline{x}'$ the transpose of $\underline{x}$ (Equation 26) and the [X] matrix is defined by Equation (18). Due to the nature of this particular experimental design and the large number of observations the value of the quadratic form is negligible compared to 1. In fact, an error of less than 1% is incurred if it is assumed to be zero. For 95% probability $z_{\alpha/2}$ is 1.96 and Equation (25) becomes

$$y' \doteq y \pm 1.96\sigma \tag{27}$$

Plots of the regression with 95% probability curves and the data are given for the damping ratio at -50°F for both materials in Figures 11 and 16.

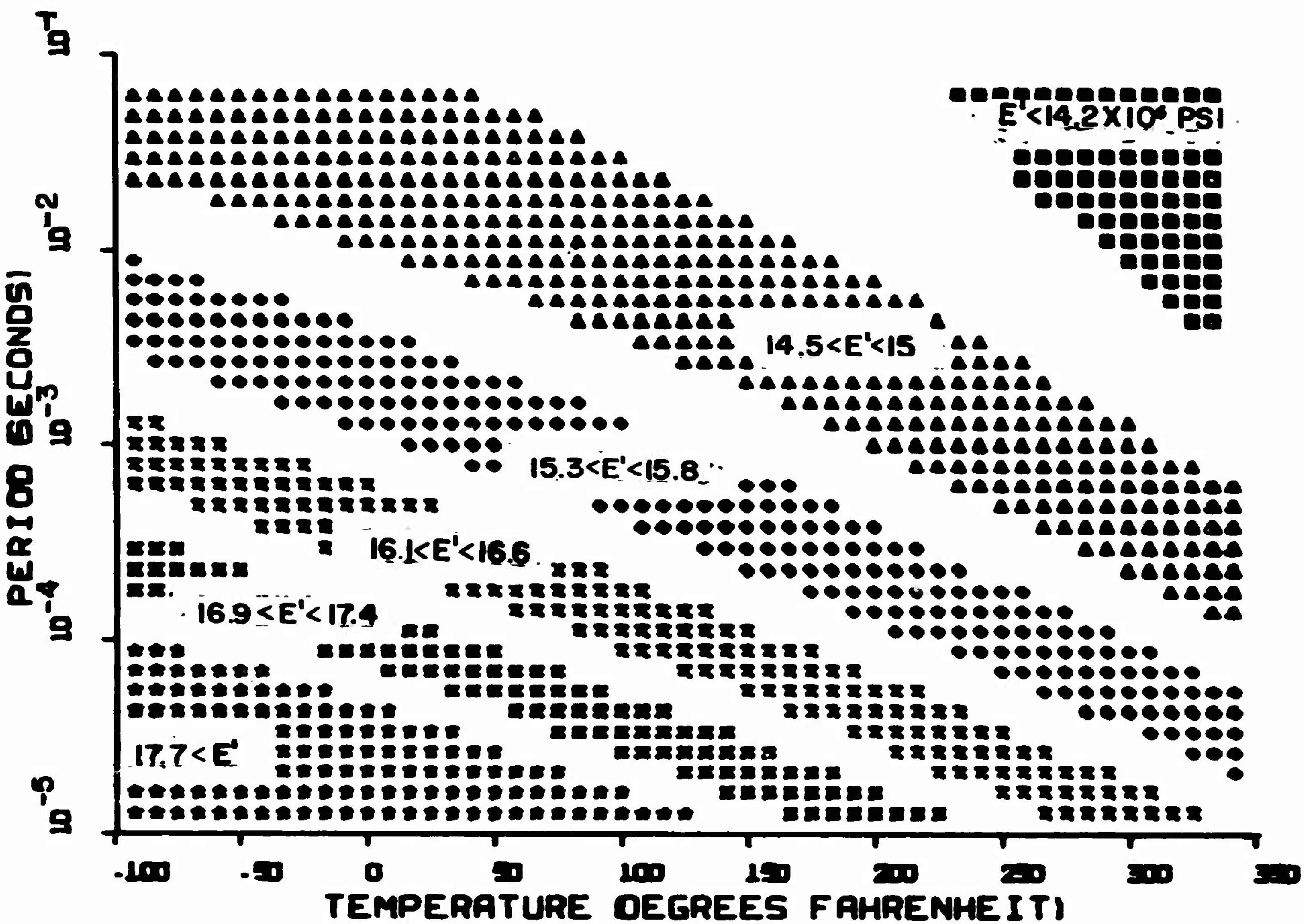

Figure 7. Contour for the Storage Modulus of Boron/Epoxy

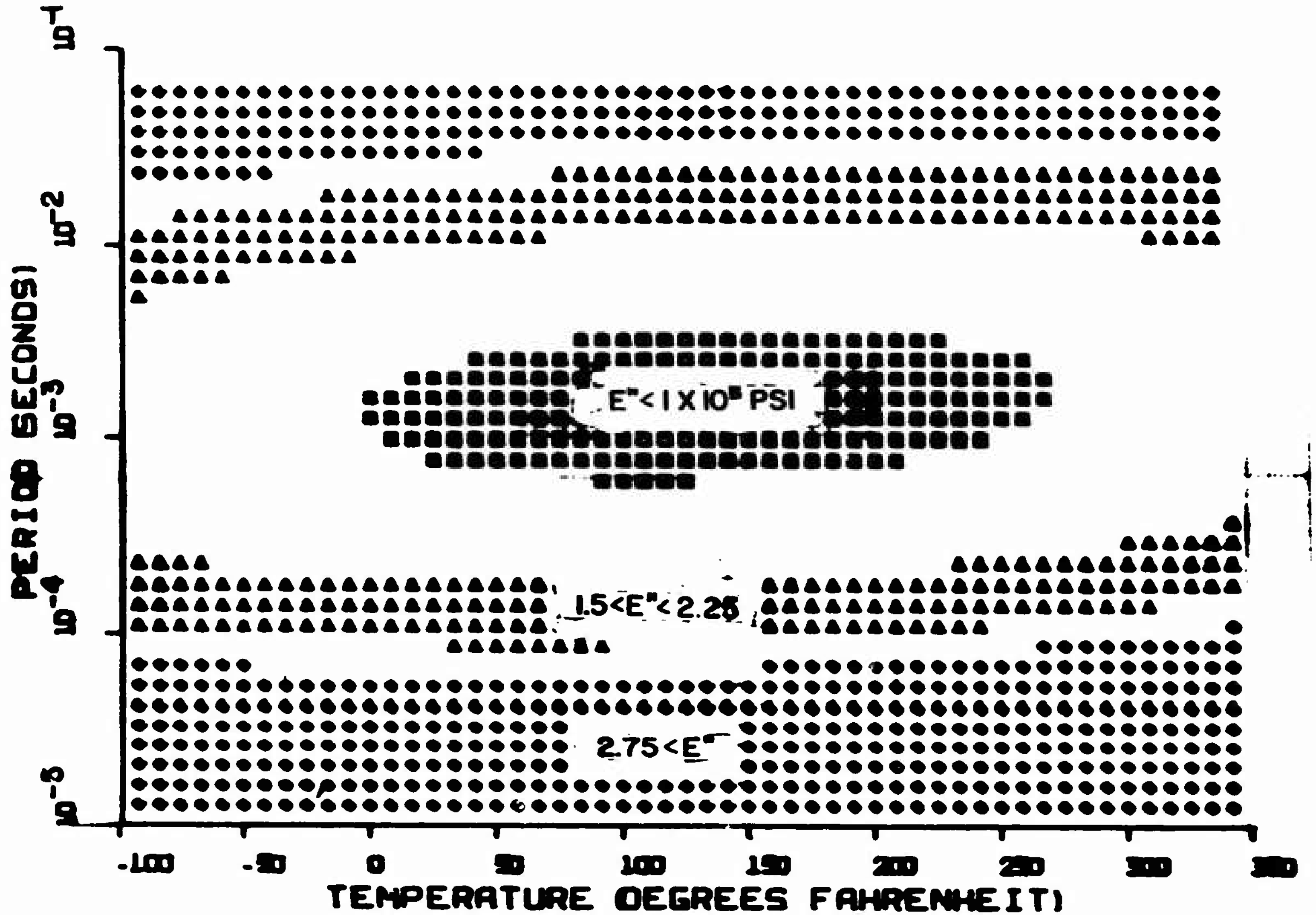

Figure 8. Contour for the Loss Modulus of Boron/Epoxy

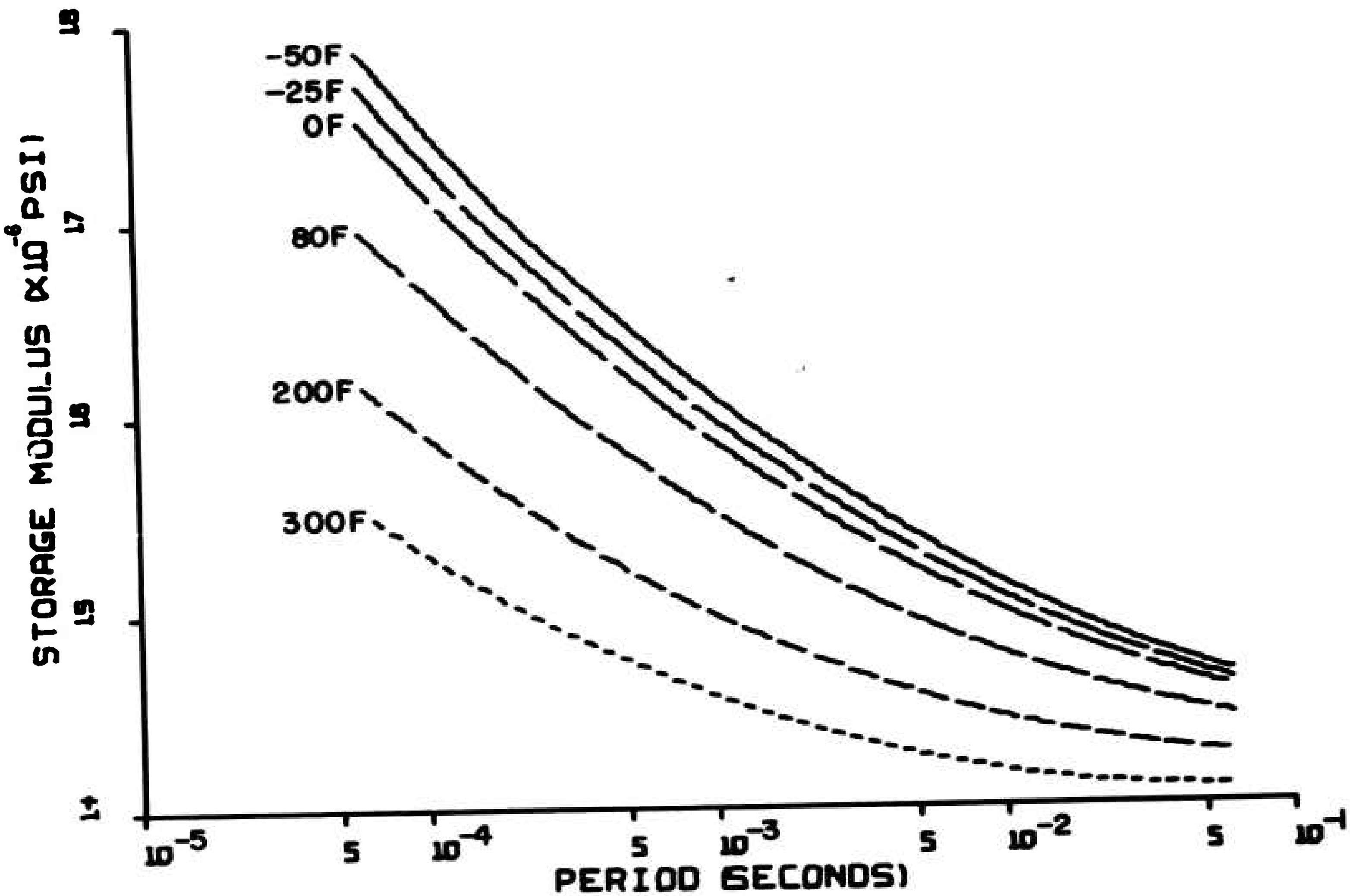

Figure 9. Constant Temperature Curves for the Storage Modulus of Boron/Epoxy

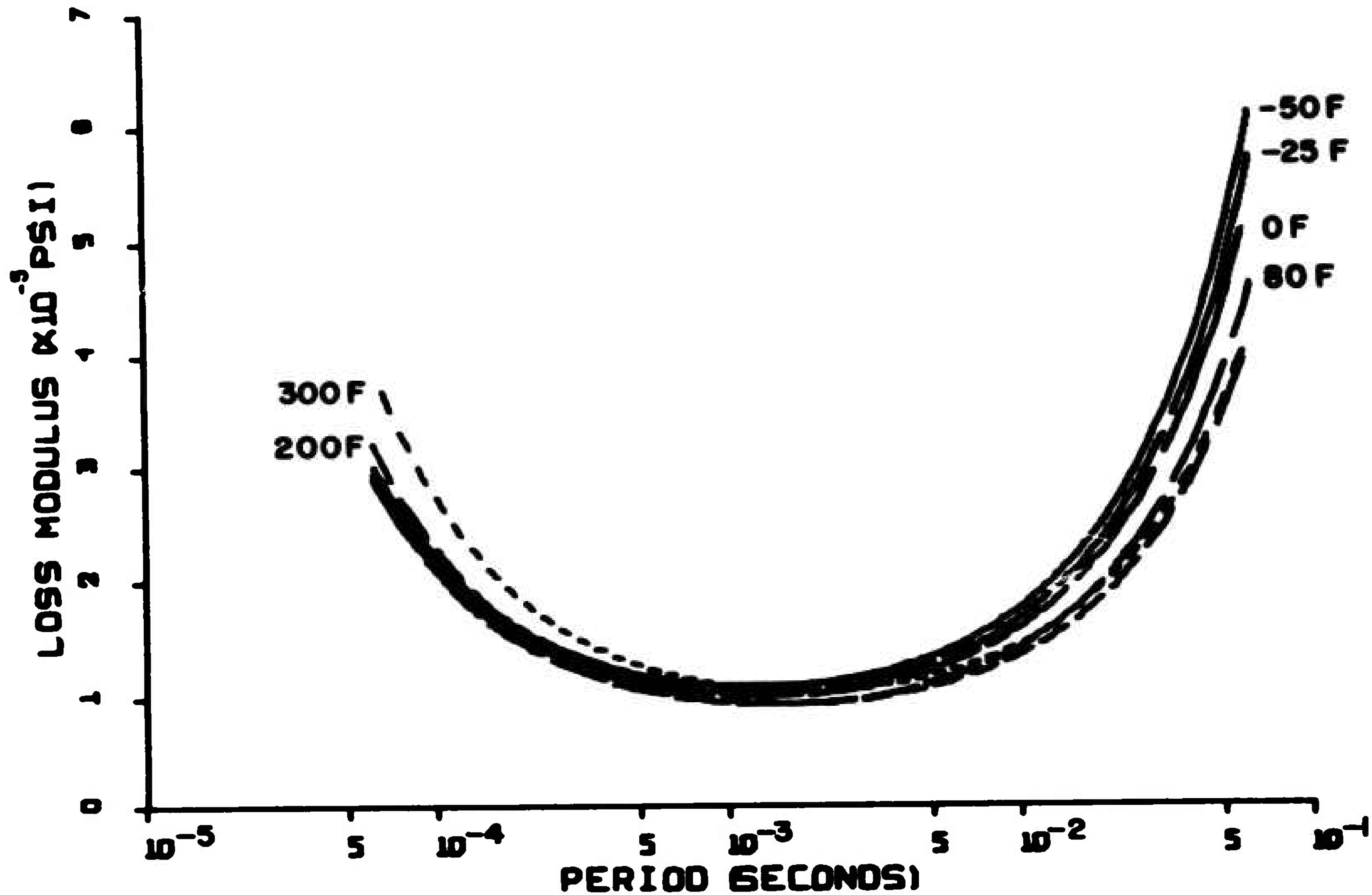

Figure 10. Constant Temperature Curves for the Loss Modulus of Boron/Epoxy

TABLE 1

R^2, σ, and the Coefficients of Equation (24) for Degrees Kelvin

Boron Epoxy

	lnδ	lnE'	lnE"
R^2	.65	.58	
σ	.33	.05	.38
A	2.42	16.48	18.90
B	1.642	-1.899×10^{-2}	1.623
C	1.115×10^{-1}	2.115×10^{-3}	1.136×10^{-1}
D	-1.352×10^{-2}	0	-1.352×10^{-2}
E	1.594×10^{-5}	0	1.594×10^{-5}
F	-5.362×10^{-4}	7.438×10^{-5}	-4.618×10^{-4}

Graphite Epoxy

	lnδ	lnE'	lnE"
R^2	.70	.25	
σ	.41	.04	.45
A	4.65	15.93	20.58
B	2.285	-7.817×10^{-3}	2.277
C	1.478×10^{-1}	1.735×10^{-3}	1.495×10^{-1}
D	-1.519×10^{-2}	3.317×10^{-4}	-1.486×10^{-2}
E	1.183×10^{-5}	0	1.183×10^{-5}
F	-1.036×10^{-3}	8.050×10^{-5}	-9.555×10^{-4}

TABLE 2

Coefficients of Equation (24) for Degrees Fahrenheit

Boron Epoxy

	$\ln\delta$	$\ln E'$	$\ln E''$
A	1.145×10^{-2}	16.48	16.49
B	1.505	0	1.505
C	1.115×10^{-1}	2.115×10^{-3}	1.136×10^{-1}
D	-2.988×10^{-3}	0	-2.988×10^{-3}
E	4.920×10^{-6}	0	4.920×10^{-6}
F	-2.979×10^{-4}	4.132×10^{-5}	-2.565×10^{-4}

Graphite Epoxy

	$\ln\delta$	$\ln E'$	$\ln E''$
A	1.547	16.01	17.56
B	2.021	1.274×10^{-2}	2.034
C	1.478×10^{-1}	1.736×10^{-3}	1.495×10^{-1}
D	-5.081×10^{-3}	1.843×10^{-4}	-4.897×10^{-3}
E	3.650×10^{-6}	0	3.650×10^{-6}
F	-5.754×10^{-4}	4.472×10^{-5}	-5.307×10^{-4}

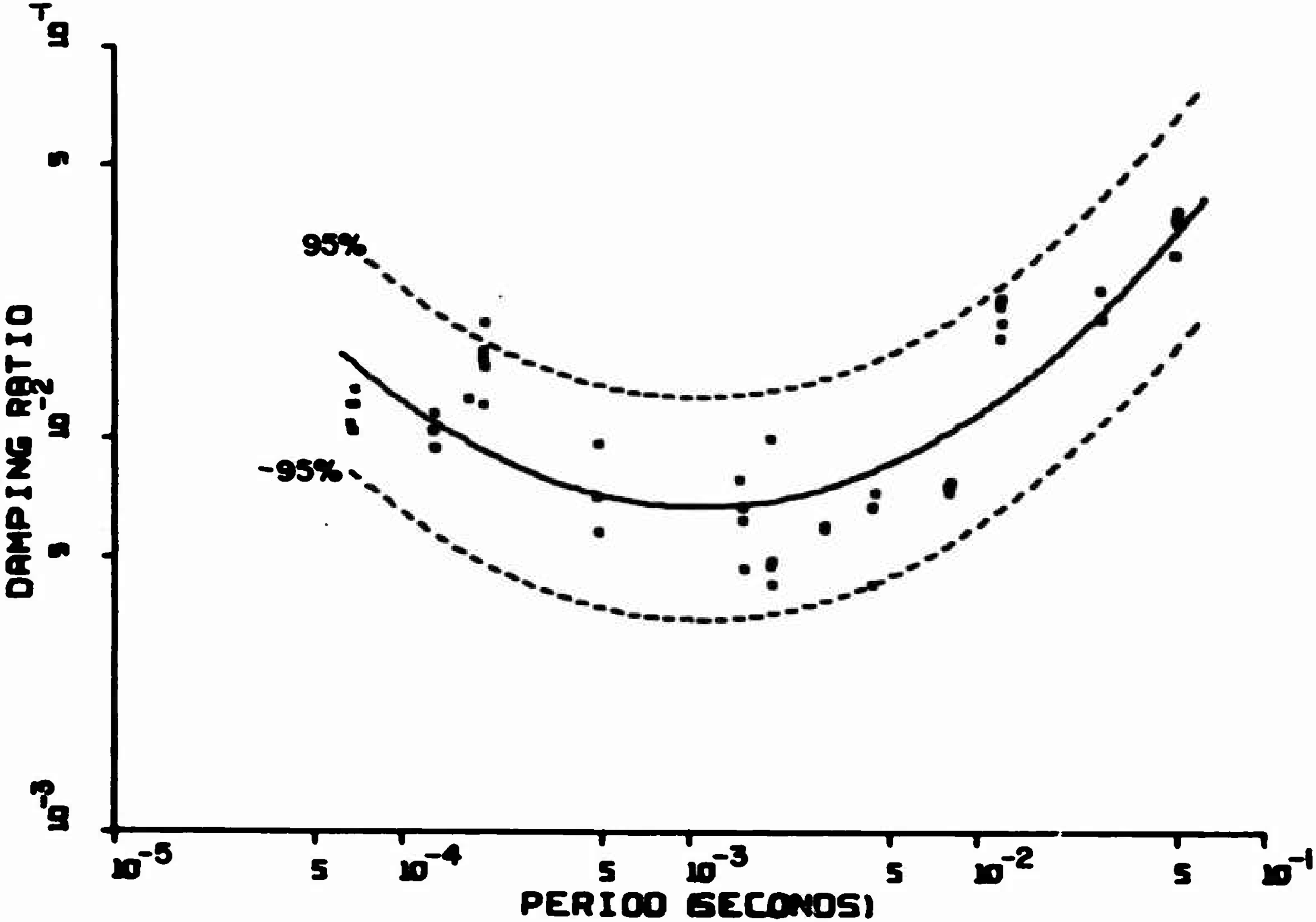

Figure 11. 95% Probability Curves for the Damping Ratio of Boron/Epoxy at -50°F

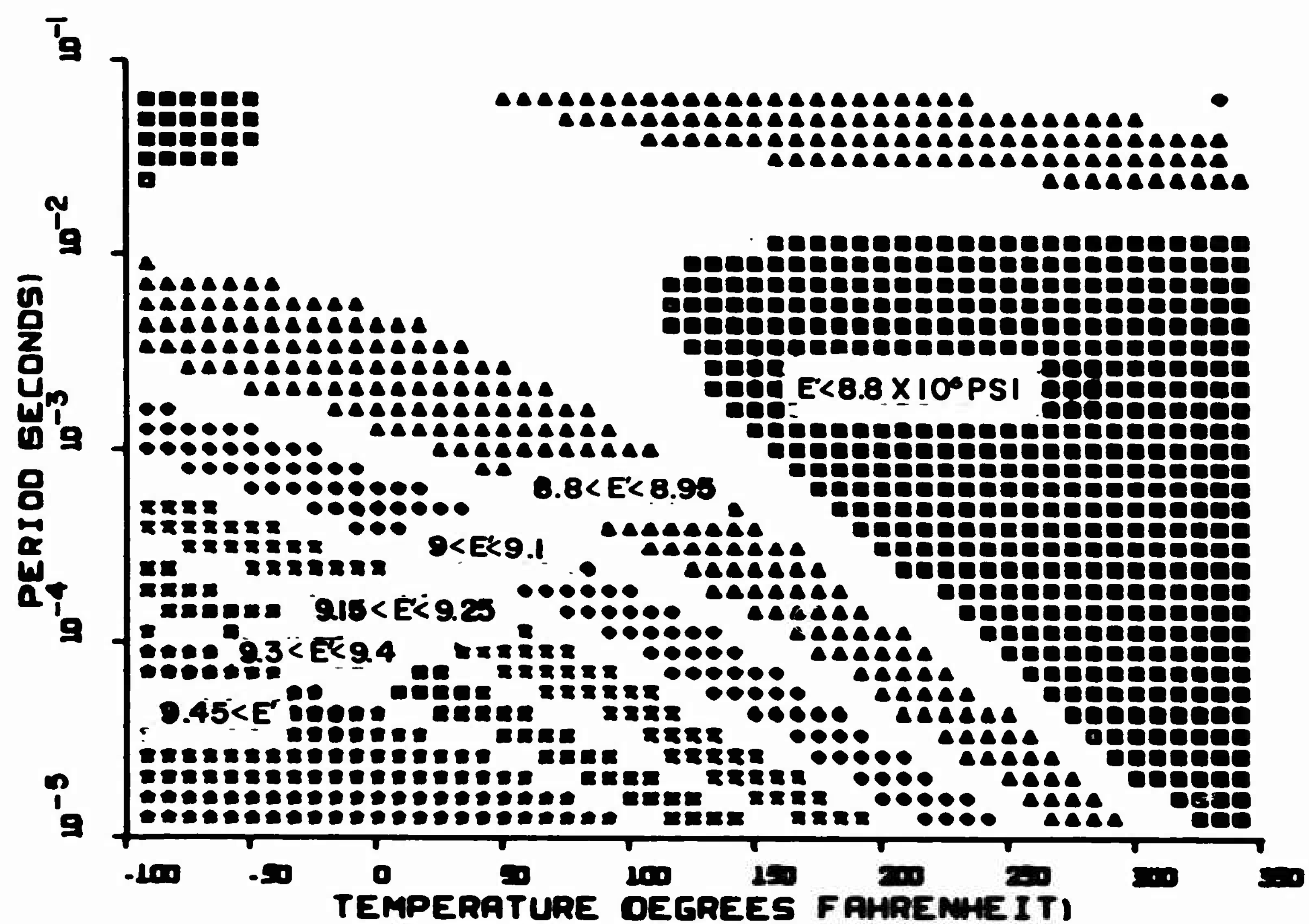

Figure 12. Contour for the Storage Modulus of Graphite/Epoxy

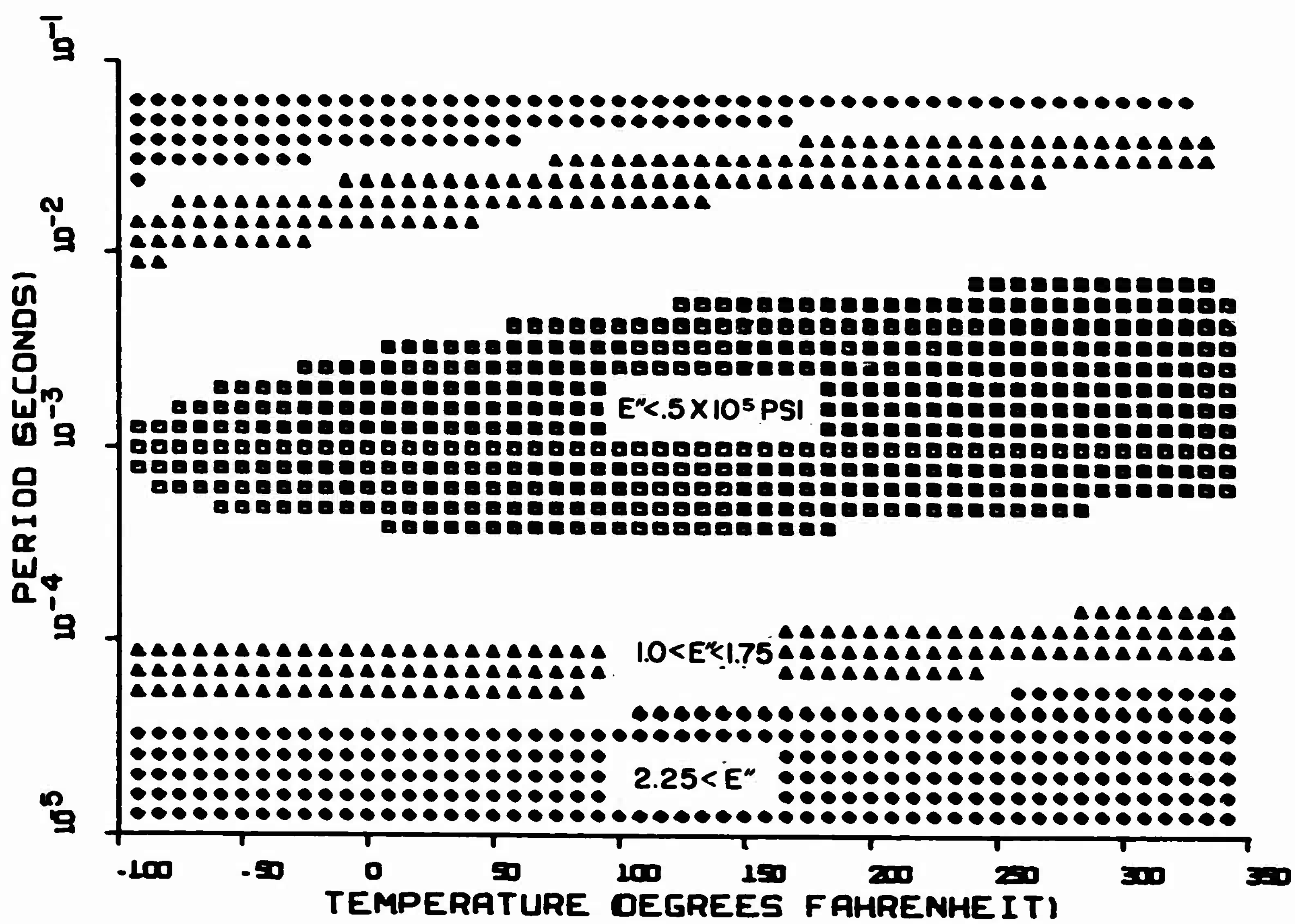

Figure 13. Contour for the Loss Modulus of Graphite/Epoxy

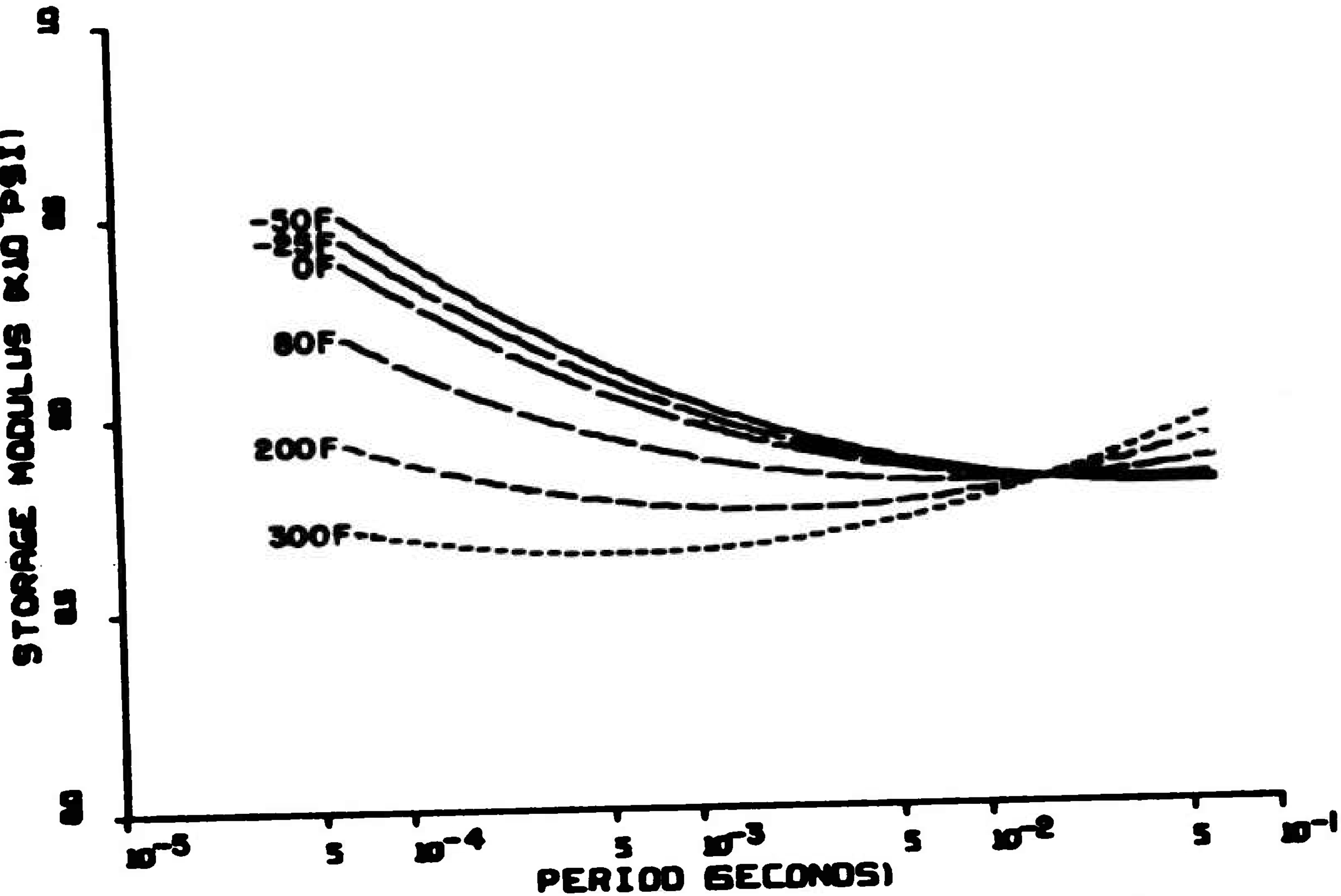

Figure 14. Constant Temperature Curves for the Storage Modulus of Graphite/Epoxy

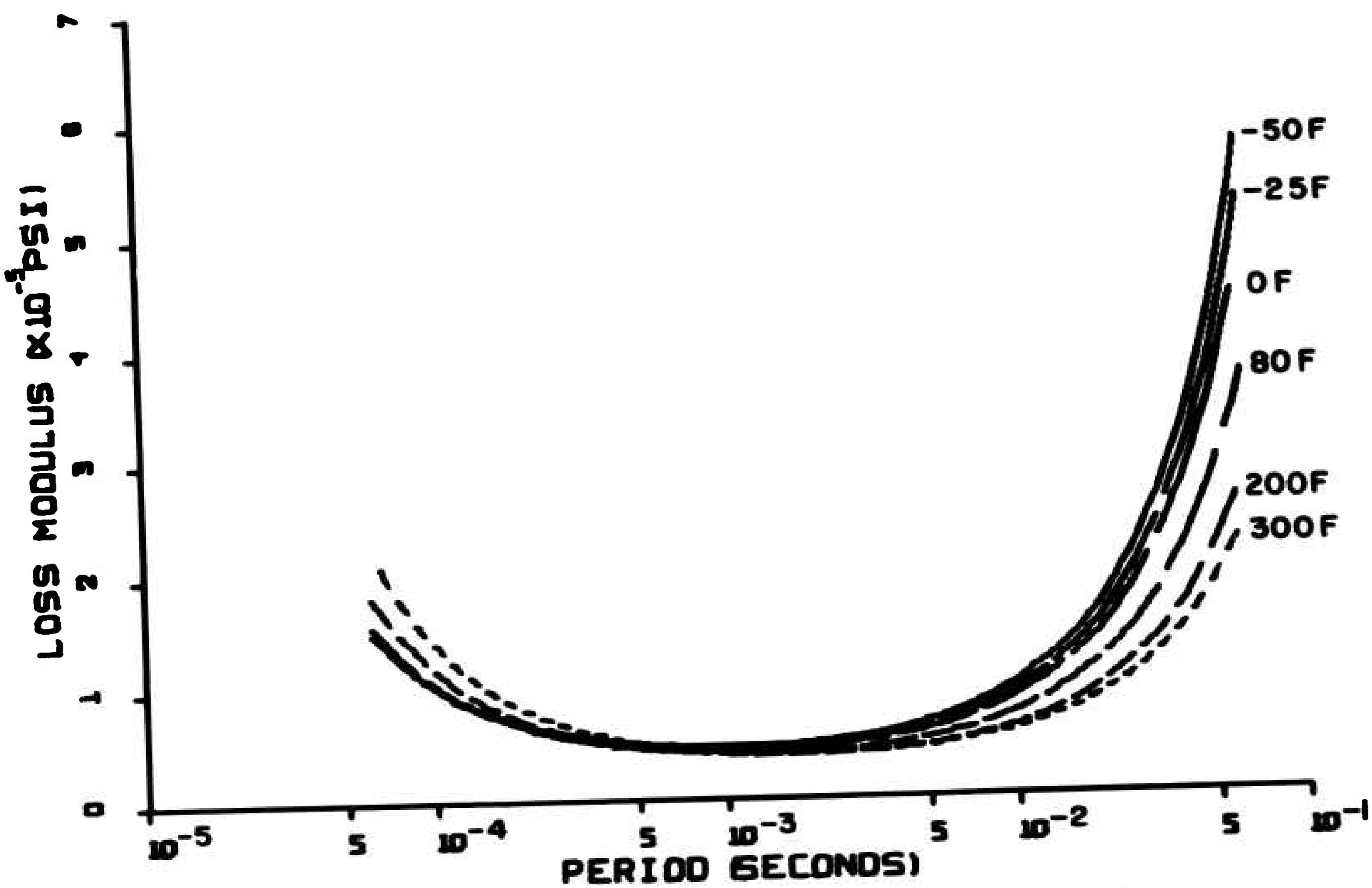

Figure 15. Constant Temperature Curves for the Loss Modulus of Graphite/Epoxy

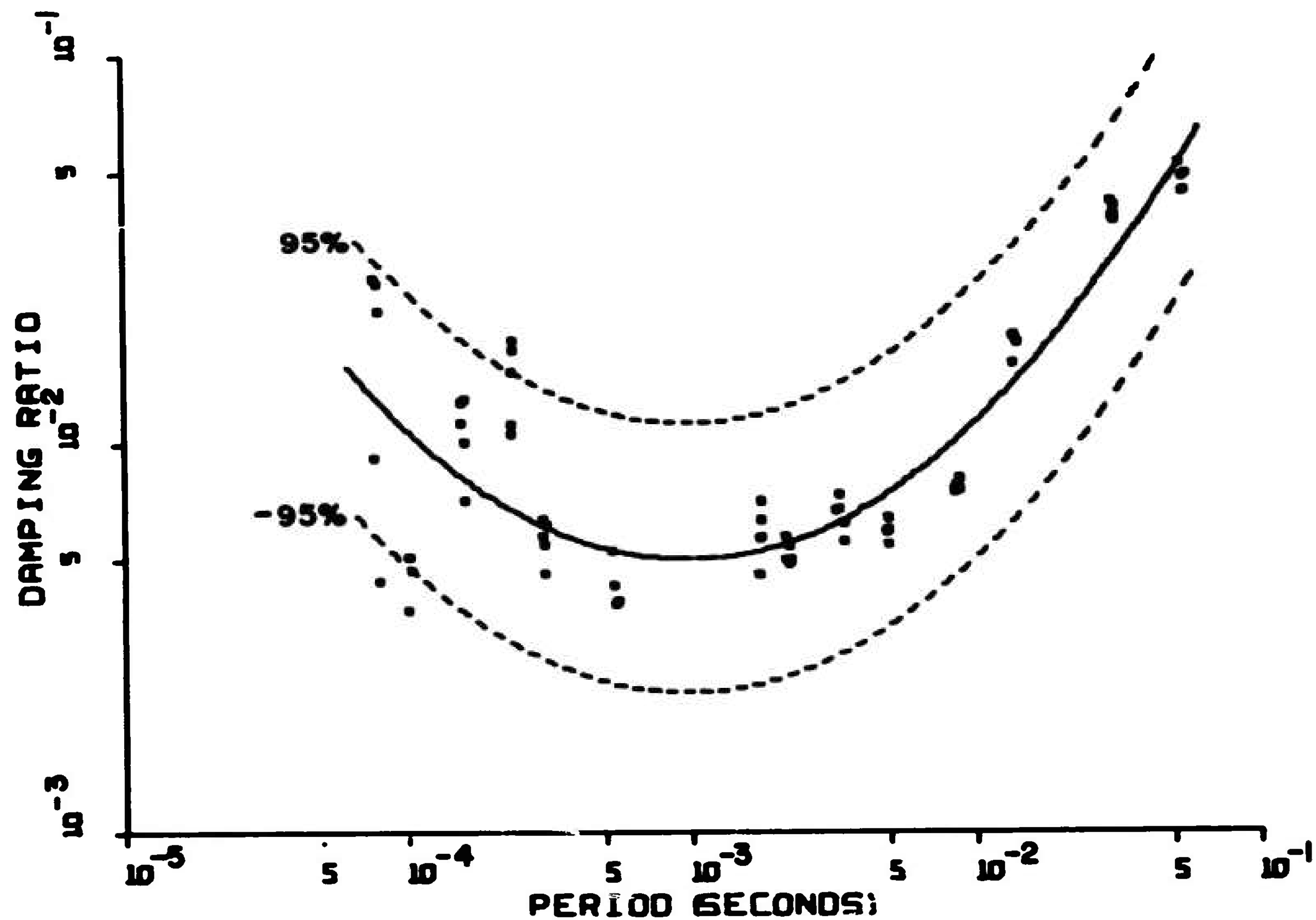

Figure 16. 95% Probability Curves for the Damping Ratio of Graphite/Epoxy at -50°F

SECTION VI

TEMPERATURE SHIFT PARAMETERS

Although response surface analysis does not necessarily give a physical explanation for the underlying principles of the material behavior, a great deal of information can be obtained from this approach.

The surface may be extrapolated to various temperature levels and to testing times.

It is also possible to compare these results with the time-temperature superposition methods of linear viscoelasticity.

Curves of storage and loss modulus versus lnt at a constant temperature can be shifted horizontally along the lnt axis with changes in temperature. A vertical shift due to density changes also exists for thermorheologically simple materials [Reference 6 Halpin].

Similar horizontal and vertical shift parameters may be established for the fiber reinforced composites tested.

The horizontal shift can be obtained from the equation of the response surface. At the reference temperature, denoted by Tr, the response (Equation 24) function becomes

$$\ln y_r = A_r + B_r x + Cx^2 \tag{29}$$

where y_r is the response (E' or E"), $x = \ln t$, $A_r = A + DT_r + ET_r^2$, and $B_r = B + FT_r$. The stationary point on the constant temperature curve (Figure 17) can be obtained by differentiating equation (29) with respect to x and equating the resulting derivative to zero.

$$\frac{d(\ln y_r)}{dx} = B_r + 2Cx = 0 \tag{30}$$

The coordinates of the stationary point are thus given by

$$x_r = -\frac{B_r}{2C}, \ln y_r = A_r - \frac{B_r^2}{4C} \tag{31}$$

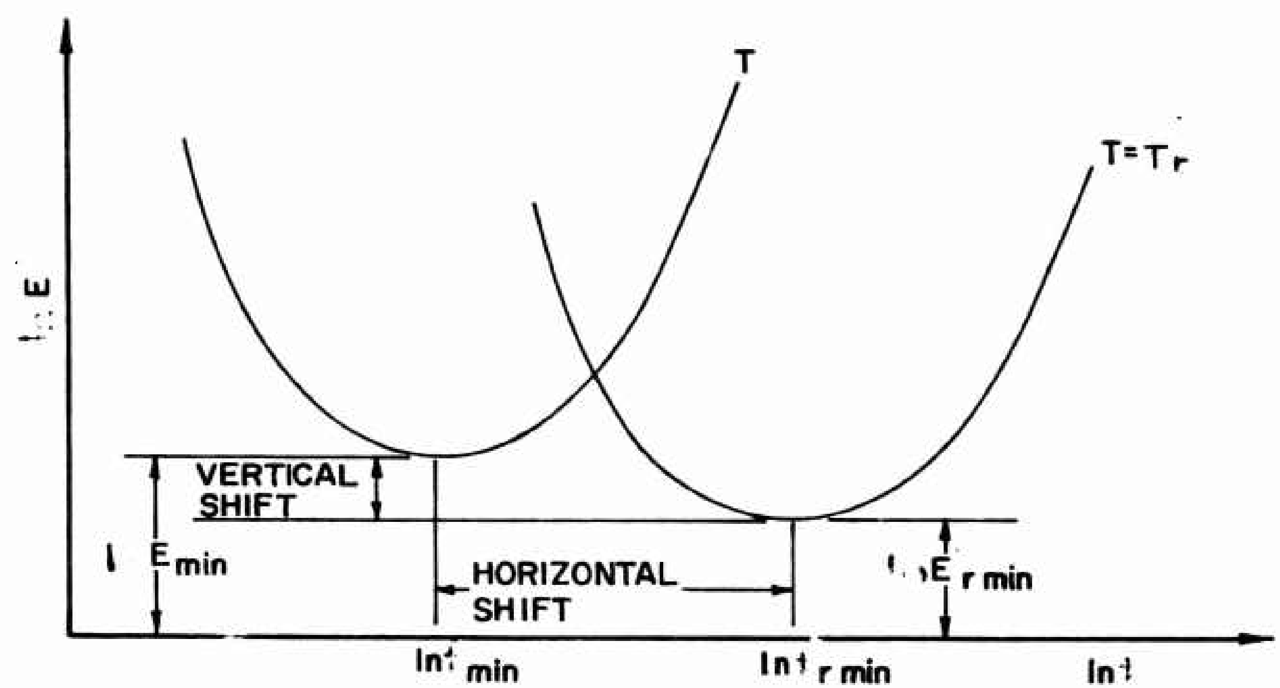

Figure 17. Horizontal and Vertical Shift

The stationary point can similarly be found for a curve at another temperature and the difference

$$x - x_r = \ln\frac{t}{t_r} = -\frac{F}{2C}\,(T - T_r) \qquad (32)$$

is the horizontal shift parameter.

The vertical shift is likewise obtained and is given by

$$\ln y - \ln y_r = \ln\frac{y}{y_r} = (D - \frac{BF}{2C})(T - T_r) + (E - \frac{F^2}{4C})\,(T^2 - T_r^{\,2}) \qquad (33)$$

Both the horizontal and vertical shifts are functions of the temperature and the regression coefficients of the response surface. The time shift exists only if C and F, the quadratic ($\ln^2 t$) and interaction ($T \ln t$) coefficients, are nonzero. The vertical shift is also a function of these coefficients. Tables 1 and 2 show that these parameters are nonzero. The shifts can be shown to be valid at all points on the curves and not just at the stationary points. Figures 18 and 19 show these shift parameters as functions of temperature with 80°F taken as the reference.

The time shift shows that an acceleration of testing time can be achieved for the storage modulus by increasing the temperature above the reference temperature. A new reduced time scale is given by $t = t_r a_T$, where t_r is the time at the reference temperature and a_T is the time shift parameter, t/t_r. For example, $\ln a_T$ for the storage modulus of graphite epoxy at 300°F is approximately -2.83 (Figure 18) and a_T is about .06, reducing the time scale to 6% of the 80°F time scale.

An increase in the time scale occurs when the temperature is elevated for the loss moduli, but this is much smaller than the decrease in time for the storage moduli.

According to Halpin [Reference 6], the storage modulus for an ideal rubber-like material should behave according to

$$\frac{E'}{E_r'} = \frac{\rho_r T_r}{\rho T} \qquad (34)$$

However, the vertical shifts obtained from these response surfaces for the storage moduli do not exhibit this behavior. For example, the largest storage modulus shift, E'/E_r', occurs for graphite epoxy

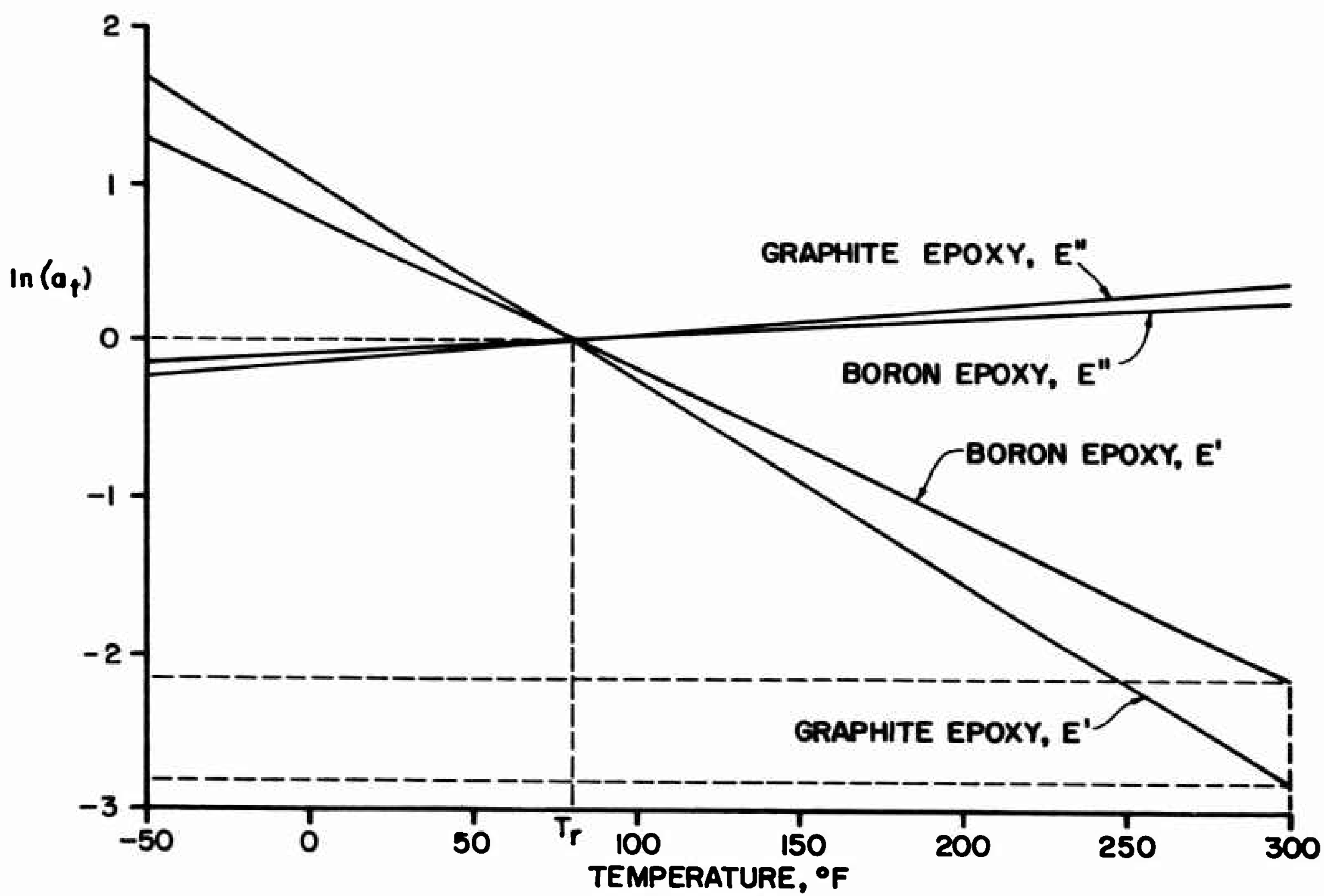

Figure 18. Time Shifts Due to Temperature Changes

and is approximately .98 at 300°F (422K) with the reference temperature being 80°F (300K). (See Figure 19). The above equation indicates a density ratio, ρ/ρ_o, of about .7 which is much larger than the actual density change. This shows that the composite materials studied here behave according to some other mechanism that is not yet understood.

Using these temperature shift parameters, master curves have been constructed for the storage moduli and are given in Figures 20 and 21.

SECTION VII

HUMIDITY EFFECTS

The response surface model given in the previous section is second order in temperature and time with an interaction term (TInt) included. To account for humidity effects a new model would include a third independent variable. This new model may be of the form

$$y = \beta_0 + \sum_{i=1}^{3} \beta_i x_i + \sum_{i=1}^{3} \beta_{ii} x_i^2 + \sum_{\substack{i \\ i<j}} \sum_{j} \beta_{ij} x_i x_j + \epsilon \qquad (35)$$

where the β's are constants, y is the measured response and ϵ is random error. The independent variables, x_1, x_2, x_3, are time, temperature, and humidity or some function of these variables.

A response surface given by Equation (35) would not only give the temperature shift parameters but would give additional shift parameters due to the absorbed water in the material.

Experiments currently being performed will be used to estimate the parameters of Equation 35.

SECTION VIII

CONCLUSIONS

A non-destructive testing technique was used to determine the environmental effects on the complex moudlus of composite materials. A large number of experiments were conducted to obtain data at various

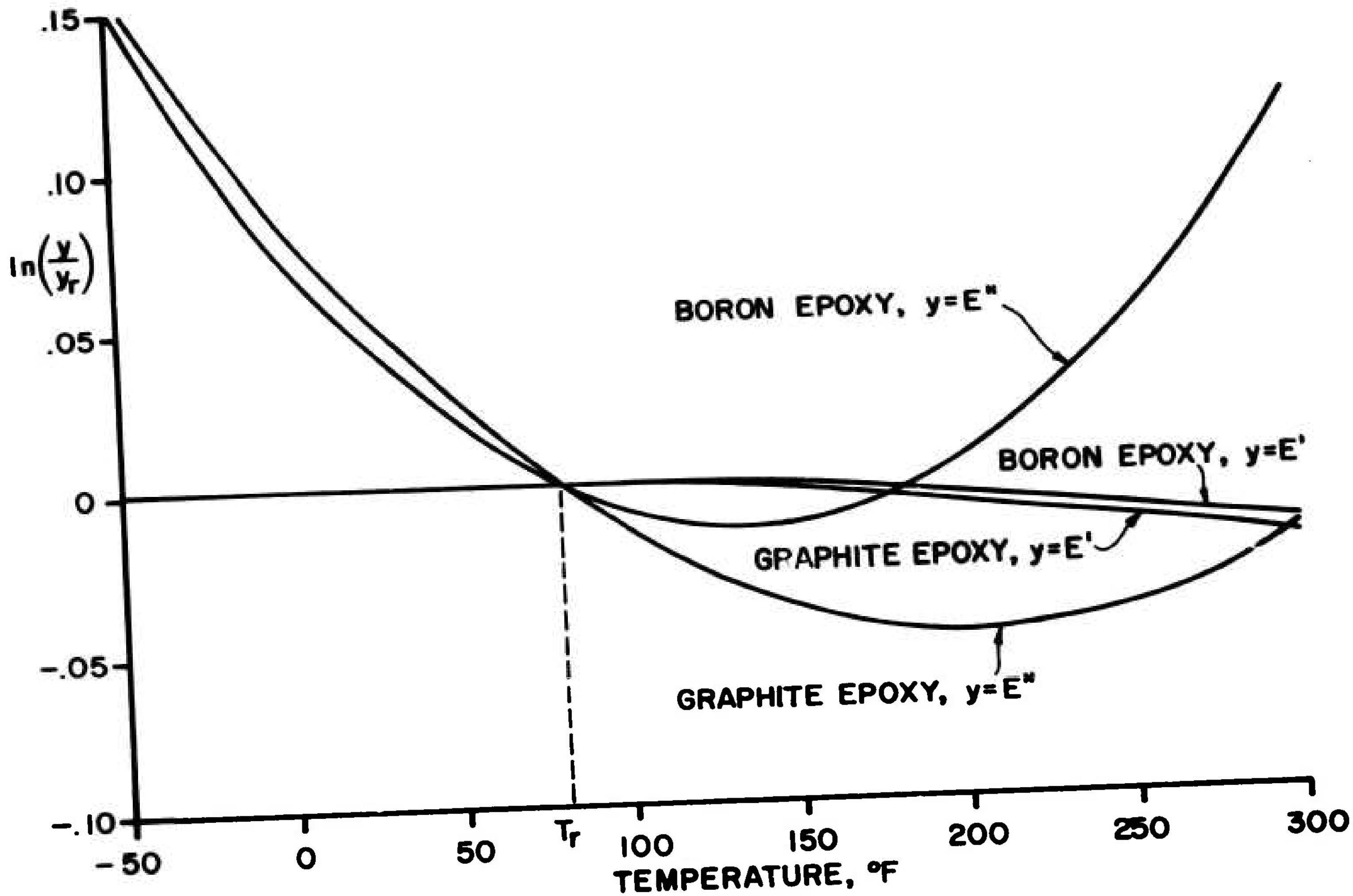

Figure 19. Vertical Shifts Due to Temperature Changes

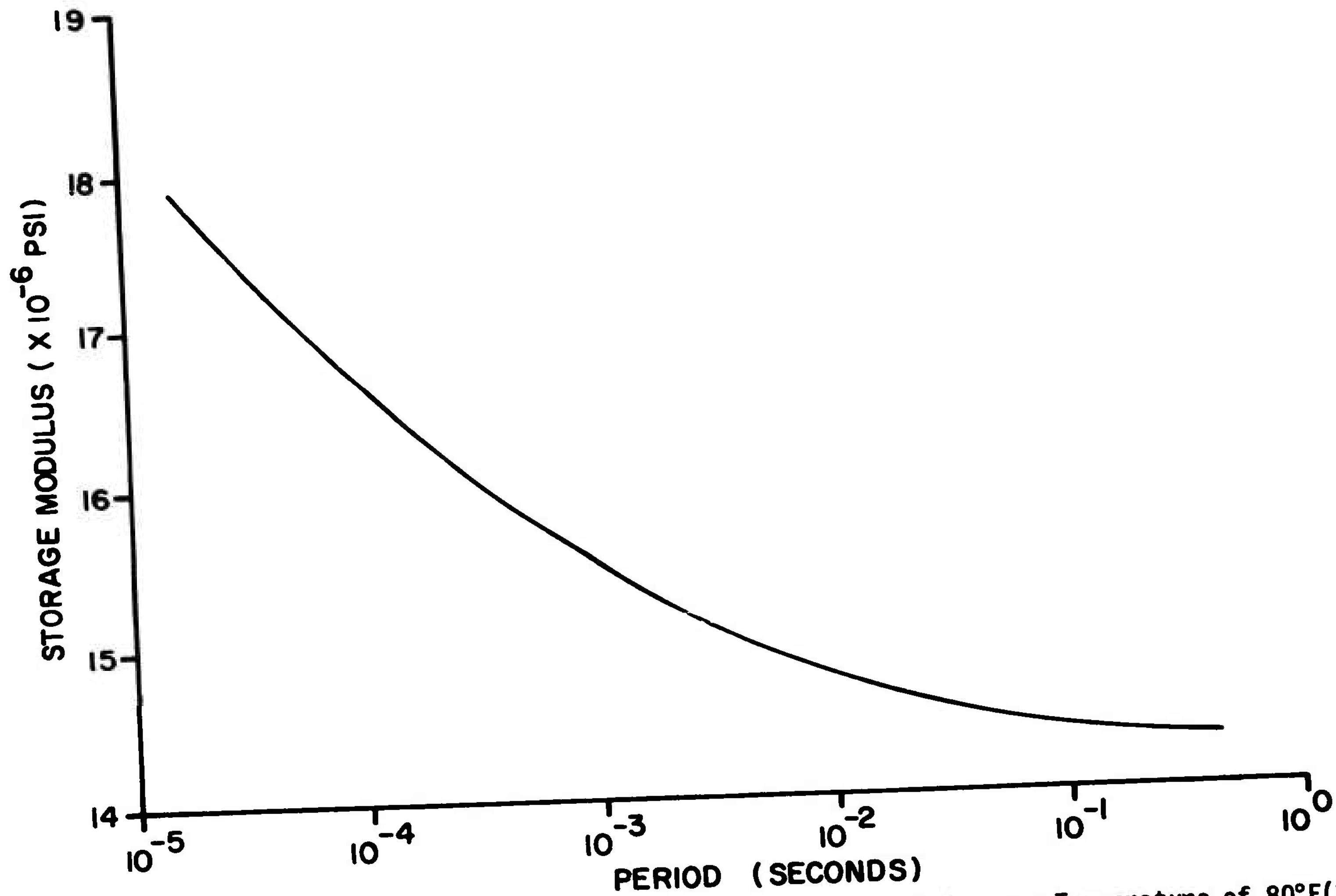

Figure 20. Master Curve for the Storage Modulus of Boron/Epoxy for a Reference Temperature of 80°F(300K)

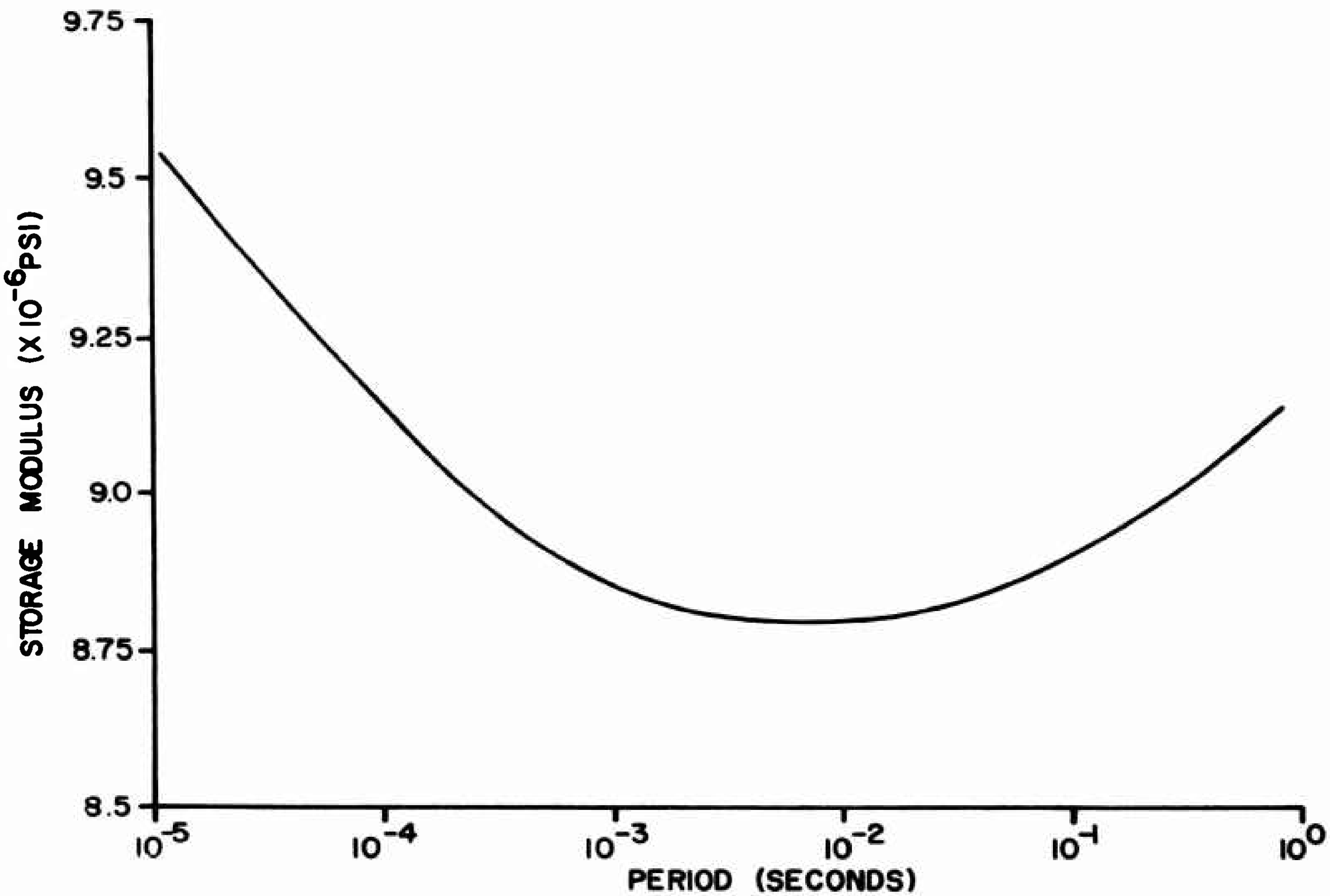

Figure 21. Master Curve for the Storage Modulus of Graphite/Epoxy for a Reference Temperature of 80°F (300K)

temperatures. These data were used to obtain response surfaces for the complex moduli of boron epoxy and graphite epoxy.

Information about the material behavior can be obtained from the equation of the response surface. Horizontal and vertical shifts were developed to show the changes in the time and vertical scales due to changes in temperature.

To develop shifts due to humidity the same procedure could be carried out after gathering sufficient humidity data to fit a response surface.

It has been shown that an appreciable acceleration of testing time can be achieved by elevating the test temperature.

APPENDIX

TABULATION OF VIBRATION DATA

The experimental observations are listed in a computer p[illegible] in order of decreasing period (increasing frequency) for each test temperature. The temperatures are given in degrees Fahrenheit and the period (which is the reciprocal of the frequency in Hertz) is given in seconds. The damping ratio is a nondimensional quantity and is computed by using equation (10). The storage modulus is given by equations (9) and (11) and is in units of psi. Each specimen is coded using two characters. The first character is numeric with the numbers 1, 2, 3, and 4 signifying transverse excitation of speicmens of length 5, 10, 15, and 20 in. respectively. The numbers 5, 6, 7, and 8 are for axial vibration and also denote lengths of 5, 10, 15, and 20 in. respectively.

The second character is alphabetic ranging from A to E. This code identifies each of five specimens having nominally identical dimensions.

Specimens were excited at the first three antiresonant frequencies. The first appearance of a code number in the tabulation signifies the lowest antiresonant frequency, second appearance identifies the next highest frequency etc.

BORON EPOXY VIBRATION DATA

TEMP	PERIOD	DAMPING RATIO	STORAGE MODULUS	SPEC
-50	0.5051E-01	0.3840E-01	0.1440E 08	4D
-50	0.5025E-01	0.3570E-01	0.1455E 08	4B
-50	0.4988E-01	0.3640E-01	0.1477E 08	4C
-50	0.4948E-01	0.2970E-01	0.1500E 08	4A
-50	0.2740E-01	0.2050E-01	0.1548E 08	3F
-50	0.2717E-01	0.2420E-01	0.1574E 08	3D
-50	0.1238E-01	0.2010E-01	0.1497E 08	2B
-50	0.1235E-01	0.2310E-01	0.1506E 08	2A
-50	0.1225E-01	0.2200E-01	0.1531E 08	2D
-50	0.1223E-01	0.1830E-01	0.1534E 08	2E
-50	0.1214E-01	0.2260E-01	0.1559E 08	2C
-50	0.8250E-02	0.7600E-02	0.1375E 08	4E
-50	0.8160E-02	0.7700E-02	0.1405E 08	4D
-50	0.8140E-02	0.7300E-02	0.1412E 08	4B
-50	0.8130E-02	0.7400E-02	0.1415E 08	4C
-50	0.8040E-02	0.7600E-02	0.1448E 08	4A
-50	0.4400E-02	0.7300E-02	0.1487E 08	3A
-50	0.4390E-02	0.6700E-02	0.1538E 08	3B
-50	0.4350E-02	0.4300E-02	0.1565E 08	3D
-50	0.2990E-02	0.6000E-02	0.1615E 08	1E
-50	0.2980E-02	0.5900E-02	0.1620E 08	1A
-50	0.1960E-02	0.4900E-02	0.1525E 08	2A
-50	0.1950E-02	0.4300E-02	0.1544E 08	2D
-50	0.1950E-02	0.4900E-02	0.1538E 08	2E
-50	0.1940E-02	0.4800E-02	0.1550E 08	2C
-50	0.1920E-02	0.1000E-01	0.1561E 08	2B
-50	0.1560E-02	0.4700E-02	0.1554E 08	3E
-50	0.1550E-02	0.6700E-02	0.1565E 08	3A
-50	0.1550E-02	0.6200E-02	0.1575E 08	3D
-50	0.1510E-02	0.7900E-02	0.1652E 08	3B
-50	0.4850E-03	0.9700E-02	0.1550E 08	1B
-50	0.4830E-03	0.5800E-02	0.1654E 08	1E
-50	0.4760E-03	0.7100E-02	0.1611E 08	1A
-50	0.1950E-03	0.1560E-01	0.1848E 08	7A
-50	0.1950E-03	0.2010E-01	0.1844E 08	7D
-50	0.1930E-03	0.1240E-01	0.1869E 08	7C
-50	0.1930E-03	0.1700E-01	0.1880E 08	7E
-50	0.1920E-03	0.1630E-01	0.1891E 08	7B
-50	0.1710E-03	0.1280E-01	0.1594E 08	1A
-50	0.1310E-03	0.9500E-02	0.1805E 08	6C
-50	0.1300E-03	0.1170E-01	0.1828E 08	6D
-50	0.1300E-03	0.1060E-01	0.1828E 08	6E
-50	0.1290E-03	0.1050E-01	0.1867E 08	6B
-50	0.6910E-04	0.1350E-01	0.1629E 08	5F
-50	0.6890E-04	0.1240E-01	0.1638E 08	5A
-50	0.6780E-04	0.1050E-01	0.1693E 08	5D

BORON EPOXY VIBRATION DATA

TEMP	PERIOD	DAMPING RATIO	STORAGE MODULUS	SPEC
-50	0.6690E-04	0.1240E-01	0.1734E 08	5C
-50	0.6690E-04	0.1100E-01	0.1654E 08	5B
-25	0.5092E-01	0.3560E-01	0.1417E 08	4E
-25	0.5051E-01	0.3550E-01	0.1440E 08	4D
-25	0.5038E-01	0.3530E-01	0.1447E 08	4B
-25	0.5030E-01	0.3470E-01	0.1452E 08	4C
-25	0.4958E-01	0.2880E-01	0.1494E 08	4A
-25	0.2746E-01	0.2170E-01	0.1541E 08	3E
-25	0.2725E-01	0.2390E-01	0.1565E 08	3D
-25	0.2683E-01	0.2240E-01	0.1613E 08	3C
-25	0.1238E-01	0.2170E-01	0.1497E 08	2A
-25	0.1235E-01	0.2160E-01	0.1506E 08	2E
-25	0.1231E-01	0.1840E-01	0.1510E 08	2C
-25	0.1226E-01	0.2140E-01	0.1529E 08	2D
-25	0.1212E-01	0.2120E-01	0.1563E 08	2B
-25	0.8265E-02	0.7600E-02	0.1369E 08	4E
-25	0.8150E-02	0.6500E-02	0.1408E 08	4B
-25	0.8130E-02	0.6600E-02	0.1416E 08	4D
-25	0.8130E-02	0.7000E-02	0.1414E 08	4C
-25	0.8080E-02	0.6900E-02	0.1431E 08	4A
-25	0.4470E-02	0.7300E-02	0.1482E 08	3A
-25	0.4440E-02	0.6700E-02	0.1505E 08	3C
-25	0.4430E-02	0.8000E-02	0.1511E 08	3B
-25	0.4300E-02	0.4400E-02	0.1559E 08	3D
-25	0.3070E-02	0.6100E-02	0.1525E 08	1C
-25	0.3050E-02	0.6100E-02	0.1565E 08	1D
-25	0.2990E-02	0.5700E-02	0.1610E 08	1A
-25	0.1970E-02	0.4900E-02	0.1514E 08	2A
-25	0.1950E-02	0.4900E-02	0.1538E 08	2F
-25	0.1950E-02	0.4700E-02	0.1523E 08	2D
-25	0.1950E-02	0.5800E-02	0.1532E 08	2C
-25	0.1920E-02	0.8500E-02	0.1581E 08	2B
-25	0.1560E-02	0.4900E-02	0.1546E 08	3E
-25	0.1560E-02	0.6900E-02	0.1546E 08	3A
-25	0.1550E-02	0.6500E-02	0.1562E 08	3B
-25	0.1550E-02	0.7700E-02	0.1577E 08	3C
-25	0.1550E-02	0.6200E-02	0.1565E 08	3D
-25	0.4670E-03	0.3900E-02	0.1528E 08	1C
-25	0.4840E-03	0.5300E-02	0.1658E 08	1D
-25	0.4600E-03	0.1200E-01	0.1583E 08	1A
-25	0.1960E-03	0.1570E-01	0.1816E 08	7A
-25	0.1950E-03	0.1580E-01	0.1840E 08	7E
-25	0.1950E-03	0.1660E-01	0.1644E 08	7B
-25	0.1940E-03	0.1570E-01	0.1851E 08	7C
-25	0.1710E-03	0.1690E-01	0.1589E 08	1A
-25	0.1340E-03	0.9600E-02	0.1744E 08	6C

BORON EPOXY VIBRATION DATA

TEMP	PERIOD	DAMPING RATIO	STORAGE MODULUS	SPEC
-25	0.1320E-03	0.1070E-01	0.1781E 08	6C
-25	0.1310E-03	0.1060E-01	0.1805E 08	6E
-25	0.1300E-03	0.8200E-02	0.1838E 08	6B
-25	0.1280E-03	0.1030E-01	0.1891E 08	6A
-25	0.6930E-04	0.1210E-01	0.1616E 08	5E
-25	0.6920E-04	0.1250E-01	0.1622E 08	5A
-25	0.6910E-04	0.1170E-01	0.1627E 08	5B
-25	0.6840E-04	0.1130E-01	0.1663E 08	5D
-25	0.6740E-04	0.1150E-01	0.1709E 08	5C
0	0.5074E-01	0.3350E-01	0.1427E 08	4F
0	0.5066E-01	0.3390E-01	0.1431E 08	4D
0	0.5051E-01	0.3280E-01	0.1440E 08	4B
0	0.5040E-01	0.3280E-01	0.1446E 08	4C
0	0.4970E-01	0.2730E-01	0.1487E 08	4A
0	0.2740E-01	0.2470E-01	0.1548E 08	3D
0	0.2721E-01	0.2150E-01	0.1570E 08	3E
0	0.2685E-01	0.2420E-01	0.1613E 08	3C
0	0.1238E-01	0.2170E-01	0.1497E 08	2A
0	0.1235E-01	0.1980E-01	0.1506E 08	2D
0	0.1231E-01	0.1840E-01	0.1516E 08	2E
0	0.1231E-01	0.1990E-01	0.1516E 08	2B
0	0.8240E-02	0.6500E-02	0.1377E 08	4E
0	0.8160E-02	0.6100E-02	0.1403E 08	4B
0	0.8150E-02	0.6500E-02	0.1409E 08	4C
0	0.8150E-02	0.6500E-02	0.1408E 08	4D
0	0.8090E-02	0.6500E-02	0.1429E 08	4A
0	0.4490E-02	0.7900E-02	0.1469E 08	3A
0	0.4440E-02	0.6700E-02	0.1498E 08	3C
0	0.4370E-02	0.6500E-02	0.1552E 08	3D
0	0.3080E-02	0.6200E-02	0.1516E 08	1C
0	0.3010E-02	0.6000E-02	0.1582E 08	1D
0	0.3010E-02	0.6000E-02	0.1582E 08	1E
0	0.2970E-02	0.5900E-02	0.1630E 08	1A
0	0.1970E-02	0.3900E-02	0.1568E 08	2A
0	0.1960E-02	0.5900E-02	0.1520E 08	2E
0	0.1950E-02	0.7600E-02	0.1535E 08	2C
0	0.1950E-02	0.5900E-02	0.1532E 08	2D
0	0.1930E-02	0.9300E-02	0.1565E 08	2B
0	0.1570E-02	0.4600E-02	0.1538E 08	3E
0	0.1560E-02	0.6500E-02	0.1556E 08	3A
0	0.1560E-02	0.6200E-02	0.1556E 08	3D
0	0.1550E-02	0.5600E-02	0.1569E 08	3C
0	0.4900E-03	0.4900E-02	0.1520E 08	1C
0	0.4850E-03	0.4900E-02	0.1550E 08	1D
0	0.4810E-03	0.1920E-01	0.1580E 08	1A
0	0.1980E-03	0.1390E-01	0.1783E 06	7A

BORON EPOXY VIBRATION DATA

TEMP	PERIOD	DAMPING RATIO	STORAGE MODULUS	SPEC
0	0.1960E-03	0.1590E-01	0.1815E 08	7E
0	0.1950E-03	0.1660E-01	0.1833E 08	7B
0	0.1950E-03	0.1480E-01	0.1837E 08	7C
0	0.1720E-03	0.1840E-01	0.1567E 08	1A
0	0.1350E-03	0.9700E-02	0.1716E 08	6C
0	0.1340E-03	0.1080E-01	0.1744E 08	6D
0	0.1320E-03	0.9500E-02	0.1766E 08	6E
0	0.1310E-03	0.9400E-02	0.1814E 08	6B
0	0.1300E-03	0.1040E-01	0.1843E 08	6A
0	0.6970E-04	0.1460E-01	0.1600E 08	5B
0	0.6950E-04	0.1290E-01	0.1607E 08	5F
0	0.6950E-04	0.1180E-01	0.1609E 08	5A
0	0.6860E-04	0.7000E-01	0.1652E 08	5D
0	0.6780E-04	0.1120E-01	0.1693E 08	5C
80	0.5040E-01	0.2470E-01	0.1446E 08	4D
80	0.5040E-01	0.2470E-01	0.1446E 08	4E
80	0.5015E-01	0.2110E-01	0.1461E 08	4B
80	0.5000E-01	0.2850E-01	0.1469E 08	4C
80	0.4963E-01	0.2090E-01	0.1489E 08	4A
80	0.2746E-01	0.1720E-01	0.1545E 08	3F
80	0.2746E-01	0.1720E-01	0.1541E 08	3C
80	0.2703E-01	0.1890E-01	0.1591E 08	3D
80	0.1246E-01	0.1560E-01	0.1478E 08	2A
80	0.1242E-01	0.1550E-01	0.1488E 08	2E
80	0.1233E-01	0.1540E-01	0.1510E 08	2C
80	0.1229E-01	0.1720E-01	0.1521E 08	2D
80	0.1198E-01	0.1680E-01	0.1601E 08	2B
80	0.8230E-02	0.5800E-02	0.1361E 08	4E
80	0.8150E-02	0.5000E-02	0.1409E 08	4C
80	0.8130E-02	0.4500E-02	0.1414E 08	4B
80	0.8110E-02	0.6300E-02	0.1422E 08	4A
80	0.8100E-02	0.5700E-02	0.1424E 08	4D
80	0.4420E-02	0.5300E-02	0.1518E 08	3C
80	0.4400E-02	0.4400E-02	0.1532E 08	3D
80	0.4390E-02	0.7500E-02	0.1538E 08	3B
80	0.3090E-02	0.6200E-02	0.1506E 08	1C
80	0.3040E-02	0.6100E-02	0.1553E 08	1A
80	0.3040E-02	0.6100E-02	0.1553E 08	1E
80	0.3030E-02	0.6100E-02	0.1563E 08	1D
80	0.1980E-02	0.5900E-02	0.1497E 08	2A
80	0.1980E-02	0.4900E-02	0.1497E 08	2C
80	0.1970E-02	0.7900E-02	0.1508E 08	2B
80	0.1970E-02	0.4700E-02	0.1511E 08	2D
80	0.1970E-02	0.4100E-02	0.1503E 08	2E
80	0.1570E-02	0.6300E-02	0.1527E 08	3A
80	0.1570E-02	0.6300E-02	0.1526E 08	3D

BORON EPOXY VIBRATION DATA

TEMP	PERIOD	DAMPING RATIO	STORAGE MODULUS	SPEC
80	0.1560E-02	0.5200E-02	0.1546E 08	3C
80	0.1560E-02	0.6300E-02	0.1546E 08	3B
80	0.1550E-02	0.3900E-02	0.1570E 08	3E
80	0.4930E-03	0.4400E-02	0.1505E 08	1C
80	0.4910E-03	0.1470E-01	0.1513E 08	1B
80	0.4900E-03	0.5400E-02	0.1520E 08	1E
80	0.4890E-03	0.5900E-02	0.1528E 08	1A
80	0.2010E-03	0.1810E-01	0.1727E 08	7D
80	0.1980E-03	0.1190E-01	0.1763E 08	7A
80	0.1980E-03	0.1610E-01	0.1780E 08	7B
80	0.1980E-03	0.1780E-01	0.1787E 08	7E
80	0.1970E-03	0.1260E-01	0.1798E 08	7C
80	0.1750E-03	0.9300E-02	0.1517E 08	1A
80	0.1350E-03	0.8500E-02	0.1697E 08	6C
80	0.1340E-03	0.1090E-01	0.1730E 08	6D
80	0.1340E-03	0.8400E-02	0.1744E 08	6E
80	0.1330E-03	0.1070E-01	0.1748E 08	6A
80	0.1310E-03	0.1060E-01	0.1809E 08	6B
80	0.7090E-04	0.1980E-01	0.1547E 08	5E
80	0.7070E-04	0.1270E-01	0.1556E 08	5A
80	0.6980E-04	0.1400E-01	0.1596E 08	5D
80	0.6860E-04	0.1060E-01	0.1650E 08	5C
200	0.5102E-01	0.2190E-01	0.1411E 08	4E
200	0.5097E-01	0.2240E-01	0.1414E 08	4D
200	0.5063E-01	0.2080E-01	0.1433E 08	4B
200	0.5056E-01	0.2020E-01	0.1437E 08	4C
200	0.5045E-01	0.2020E-01	0.1443E 08	4A
200	0.2811E-01	0.1760E-01	0.1472E 08	3E
200	0.2801E-01	0.1820E-01	0.1481E 08	3D
200	0.2753E-01	0.1720E-01	0.1534E 08	3C
200	0.1270E-01	0.1580E-01	0.1424E 08	2C
200	0.1258E-01	0.1250E-01	0.1451E 08	2E
200	0.1256E-01	0.1260E-01	0.1455E 08	2A
200	0.1250E-01	0.1630E-01	0.1455E 08	2D
200	0.1238E-01	0.1550E-01	0.1497E 08	2B
200	0.8300E-02	0.5800E-02	0.1358E 08	4E
200	0.8200E-02	0.5300E-02	0.1391E 08	4B
200	0.8180E-02	0.5300E-02	0.1397E 08	4D
200	0.8160E-02	0.5500E-02	0.1403E 08	4A
200	0.8160E-02	0.5400E-02	0.1406E 08	4C
200	0.4510E-02	0.7300E-02	0.1458E 08	3A
200	0.4460E-02	0.4500E-02	0.1485E 08	3D
200	0.4450E-02	0.6700E-02	0.1491E 08	3B
200	0.4430E-02	0.7700E-02	0.1511E 08	3C
200	0.3100E-02	0.1240E-01	0.1497E 08	1C
200	0.3070E-02	0.6700E-02	0.1525E 08	1B

BORON EPOXY VIBRATION DATA

TEMP	PERIOD	DAMPING RATIO	STORAGE MODULUS	SPEC
200	0.3070E-02	0.6100E-02	0.1521E 08	1A
200	0.3060E-02	0.6100E-02	0.1534E 08	1E
200	0.3050E-02	0.6100E-02	0.1543E 08	1D
200	0.2020E-02	0.1000E-01	0.1438E 08	2C
200	0.2010E-02	0.6000E-02	0.1450E 08	2E
200	0.2000E-02	0.6000E-02	0.1461E 08	2D
200	0.2000E-02	0.7200E-02	0.1461E 08	2A
200	0.1990E-02	0.8000E-02	0.1473E 08	2B
200	0.1610E-02	0.6700E-02	0.1465E 08	3A
200	0.1590E-02	0.6600E-02	0.1498E 08	3B
200	0.1590E-02	0.4600E-02	0.1490E 08	3E
200	0.1590E-02	0.6500E-02	0.1498E 08	3C
200	0.1590E-02	0.6400E-02	0.1489E 08	3D
200	0.4980E-03	0.4500E-02	0.1476E 08	1D
200	0.4980E-03	0.8900E-02	0.1476E 08	1B
200	0.4960E-03	0.6000E-02	0.1483E 08	1C
200	0.4950E-03	0.8400E-02	0.1491E 08	1A
200	0.2040E-03	0.1430E-01	0.1672E 08	7A
200	0.2040E-03	0.2200E-01	0.1686E 08	7E
200	0.2040E-03	0.1530E-01	0.1672E 08	7D
200	0.2030E-03	0.1640E-01	0.1703E 08	7C
200	0.2020E-03	0.1460E-01	0.1710E 08	7B
200	0.1900E-03	0.8600E-02	0.1250E 08	1D
200	0.1810E-03	0.7200E-02	0.1420E 08	1B
200	0.1800E-03	0.1440E-01	0.1435E 08	1E
200	0.1790E-03	0.9600E-02	0.1447E 08	1A
200	0.1400E-03	0.1010E-01	0.1593E 08	6C
200	0.1390E-03	0.6700E-02	0.1620E 08	6D
200	0.1370E-03	0.1100E-01	0.1656E 08	6A
200	0.1360E-03	0.8600E-02	0.1673E 08	6E
200	0.1340E-03	0.1080E-01	0.1739E 08	6B
200	0.7260E-04	0.2390E-01	0.1475E 08	5E
200	0.7170E-04	0.1290E-01	0.1512E 08	5A
200	0.7130E-04	0.1710E-01	0.1530E 08	5D
200	0.7000E-04	0.1640E-01	0.1567E 08	5C
300	0.5160E-01	0.2170E-01	0.1380E 08	4E
300	0.5144E-01	0.2060E-01	0.1388E 08	4C
300	0.5134E-01	0.2130E-01	0.1394E 08	4D
300	0.5110E-01	0.1940E-01	0.1407E 08	4B
300	0.5084E-01	0.2080E-01	0.1421E 08	4A
300	0.2833E-01	0.1700E-01	0.1448E 08	3D
300	0.2804E-01	0.1750E-01	0.1478E 08	3E
300	0.2797E-01	0.1750E-01	0.1485E 08	3C
300	0.1278E-01	0.1340E-01	0.1406E 08	2C
300	0.1274E-01	0.1810E-01	0.1415E 08	2D
300	0.1274E-01	0.1400E-01	0.1415E 08	2E

BORON EPOXY VIBRATION DATA

TEMP	PERIOD	DAMPING RATIO	STORAGE MODULUS	SPEC
300	0.1274E-01	0.1430E-01	0.1415E 08	2A
300	0.1262E-01	0.1890E-01	0.1442E 08	2B
300	0.8370E-02	0.7100E-02	0.1335E 08	4E
300	0.8320E-02	0.8300E-02	0.1351E 08	4C
300	0.8300E-02	0.7100E-02	0.1358E 08	4B
300	0.8260E-02	0.7400E-02	0.1369E 08	4A
300	0.8260E-02	0.6100E-02	0.1369E 08	4D
300	0.4580E-02	0.7800E-02	0.1413E 08	3A
300	0.4520E-02	0.6800E-02	0.1452E 08	3D
300	0.4510E-02	0.5600E-02	0.1458E 08	3C
300	0.4480E-02	0.7800E-02	0.1472E 08	3B
300	0.3120E-02	0.2180E-01	0.1479E 08	1C
300	0.3110E-02	0.1240E-01	0.1488E 08	1E
300	0.3090E-02	0.6200E-02	0.1506E 08	1D
300	0.2060E-02	0.1150E-01	0.1378E 08	2C
300	0.2060E-02	0.1340E-01	0.1375E 08	2E
300	0.2040E-02	0.1020E-01	0.1409E 08	2D
300	0.2030E-02	0.7300E-02	0.1421E 08	2A
300	0.2030E-02	0.1220E-01	0.1418E 08	2B
300	0.1620E-02	0.7000E-02	0.1443E 08	3B
300	0.1620E-02	0.6700E-02	0.1443E 08	3E
300	0.1620E-02	0.7000E-02	0.1442E 08	3A
300	0.1620E-02	0.8100E-02	0.1442E 08	3D
300	0.1610E-02	0.7500E-02	0.1458E 08	3C
300	0.5060E-03	0.1510E-01	0.1425E 08	1A
300	0.5040E-03	0.5000E-02	0.1439E 08	1E
300	0.5040E-03	0.5000E-02	0.1439E 08	1C
300	0.2090E-03	0.1050E-01	0.1598E 08	7C
300	0.2090E-03	0.1320E-01	0.1598E 08	7B
300	0.2090E-03	0.1270E-01	0.1601E 08	7D
300	0.2070E-03	0.1320E-01	0.1635E 08	7E
300	0.2060E-03	0.1030E-01	0.1645E 08	7A
300	0.1930E-03	0.9000E-02	0.1247E 08	1D
300	0.1900E-03	0.8900E-02	0.1294E 08	1E
300	0.1420E-03	0.1920E-01	0.1540E 08	6C
300	0.1400E-03	0.1390E-01	0.1580E 08	6D
300	0.1390E-03	0.8100E-02	0.1616E 08	6E
300	0.1390E-03	0.1390E-01	0.1611E 08	6A
300	0.1370E-03	0.1110E-01	0.1656E 08	6B
300	0.7440E-04	0.3050E-01	0.1404E 08	5E
300	0.7270E-04	0.1530E-01	0.1469E 08	5A
300	0.7210E-04	0.1980E-01	0.1495E 08	5D
300	0.7160E-04	0.2080E-01	0.1514E 08	5B
300	0.7120E-04	0.1710E-01	0.1532E 08	5C

GRAPHITE EPOXY VIBRATION DATA

TEMP	PERIOD	DAMPING RATIO	STORAGE MODULUS	SPEC
-50	0.5530E-01	0.4430E-01	0.8800E 07	4A
-50	0.5490E-01	0.4840E-01	0.8920E 07	4B
-50	0.5460E-01	0.4420E-01	0.9040E 07	4E
-50	0.5320E-01	0.5270E-01	0.9520E 07	4C
-50	0.3160E-01	0.4050E-01	0.8520E 07	3B
-50	0.3160E-01	0.3850E-01	0.8540E 07	3A
-50	0.3140E-01	0.3700E-01	0.8650E 07	3D
-50	0.3100E-01	0.3780E-01	0.8890E 07	3E
-50	0.3060E-01	0.4160E-01	0.9090E 07	3C
-50	0.1430E-01	0.1780E-01	0.8260E 07	2C
-50	0.1400E-01	0.1820E-01	0.8610E 07	2B
-50	0.1590E-01	0.1670E-01	0.8760E 07	2A
-50	0.1370E-01	0.1850E-01	0.8970E 07	2D
-50	0.1370E-01	0.1560E-01	0.8960E 07	2E
-50	0.8910E-02	0.8110E-02	0.8630E 07	4D
-50	0.8890E-02	0.7560E-02	0.8680E 07	4A
-50	0.8740E-02	0.7870E-02	0.8800E 07	4B
-50	0.8610E-02	0.7700E-02	0.9260E 07	4E
-50	0.8510E-02	0.7550E-02	0.9470E 07	4C
-50	0.5000E-02	0.5500E-02	0.8680E 07	3A
-50	0.4990E-02	0.6020E-02	0.6710E 07	3E
-50	0.4980E-02	0.5970E-02	0.8760E 07	3B
-50	0.4970E-02	0.6450E-02	0.8800E 07	3D
-50	0.4890E-02	0.5940E-02	0.9090E 07	3C
-50	0.3480E-02	0.6260E-02	0.8690E 07	1C
-50	0.3470E-02	0.5610E-02	0.8720E 07	1B
-50	0.3370E-02	0.6780E-02	0.9250E 07	1E
-50	0.3350E-02	0.7400E-02	0.9390E 07	1D
-50	0.3270E-02	0.6740E-02	0.9840E 07	1A
-50	0.2270E-02	0.4990E-02	0.8340E 07	2C
-50	0.2240E-02	0.5430E-02	0.8550E 07	2B
-50	0.2220E-02	0.4870E-02	0.8690E 07	2A
-50	0.2180E-02	0.5770E-02	0.9040E 07	2D
-50	0.2180E-02	0.5000E-02	0.9020E 07	2E
-50	0.1790E-02	0.5750E-02	0.8660E 07	3A
-50	0.1780E-02	0.6380E-02	0.8740E 07	3B
-50	0.1760E-02	0.7130E-02	0.8710E 07	3E
-50	0.1770E-02	0.5690E-02	0.8800E 07	3D
-50	0.1750E-02	0.4580E-02	0.9080E 07	3C
-50	0.5600E-03	0.3900E-02	0.8540E 07	1C
-50	0.5550E-03	0.3890E-02	0.8700E 07	1B
-50	0.5470E-03	0.3830E-02	0.8960E 07	1E
-50	0.5360E-03	0.4300E-02	0.9310E 07	1D
-50	0.5290E-03	0.5290E-02	0.9570E 07	1A
-50	0.3097E-03	0.6200E-02	0.9510E 07	8B
-50	0.3070E-03	0.5500E-02	0.9670E 07	8A

GRAPHITE EPOXY VIBRATION DATA

TEMP	PERIOD	DAMPING RATIO	STORAGE MODULUS	SPEC
-50	0.3049E-03	0.4600E-02	0.9810E 07	8D
-50	0.3025E-03	0.6400E-02	0.9960E 07	8C
-50	0.3022E-03	0.5800E-02	0.9980E 07	8E
-50	0.2384E-03	0.1720E-01	0.9020E 07	7D
-50	0.2379E-03	0.1820E-01	0.9200E 07	7E
-50	0.2349E-03	0.1060E-01	0.9300E 07	7C
-50	0.2349E-03	0.1510E-01	0.9290E 07	7B
-50	0.2348E-03	0.1120E-01	0.9300E 07	7A
-50	0.1606E-03	0.1290E-01	0.8630E 07	6B
-50	0.1605E-03	0.7200E-02	0.8840E 07	6A
-50	0.1602E-03	0.1010E-01	0.8880E 07	6E
-50	0.1572E-03	0.1130E-01	0.9220E 07	6D
-50	0.1572E-03	0.1270E-01	0.9220E 07	6C
-50	0.1035E-03	0.4700E-02	0.9440E 07	8B
-50	0.1028E-03	0.5100E-02	0.9570E 07	3A
-50	0.1020E-03	0.5100E-02	0.9730E 07	8C
-50	0.1016E-03	0.3700E-02	0.9810E 07	8D
-50	0.1012E-03	0.5100E-02	0.9890E 07	8E
-50	0.7990E-04	0.4400E-02	0.8910E 07	5A
-50	0.7960E-04	0.2160E-01	0.8980E 07	5D
-50	0.7860E-04	0.2540E-01	0.9220E 07	5E
-50	0.7690E-04	0.2610E-01	0.9640E 07	5C
-50	0.7650E-04	0.9200E-02	0.9740E 07	5B
-25	0.5600E-01	0.4710E-01	0.8580E 07	4D
-25	0.5530E-01	0.4260E-01	0.8810E 07	4A
-25	0.5490E-01	0.4400E-01	0.8920E 07	4B
-25	0.5460E-01	0.4370E-01	0.9020E 07	4E
-25	0.5320E-01	0.5000E-01	0.9520E 07	4C
-25	0.3160E-01	0.3610E-01	0.8510E 07	3A
-25	0.3150E-01	0.3560E-01	0.8620E 07	3D
-25	0.3150E-01	0.3590E-01	0.8600E 07	3B
-25	0.3110E-01	0.3730E-01	0.8840E 07	3E
-25	0.3060E-01	0.3800E-01	0.9080E 07	3C
-25	0.1430E-01	0.1860E-01	0.8190E 07	2C
-25	0.1400E-01	0.1610E-01	0.8580E 07	2B
-25	0.1390E-01	0.1740E-01	0.8700E 07	2A
-25	0.1370E-01	0.1610E-01	0.8950E 07	2D
-25	0.1370E-01	0.1610E-01	0.8910E 07	2E
-25	0.8940E-02	0.7600E-02	0.8570E 07	4D
-25	0.8920E-02	0.7690E-02	0.8620E 07	4A
-25	0.8770E-02	0.7680E-02	0.8910E 07	4B
-25	0.8640E-02	0.7500E-02	0.9200E 07	4E
-25	0.8560E-02	0.7490E-02	0.9360E 07	4C
-25	0.5010E-02	0.4510E-02	0.8630E 07	3A
-25	0.5000E-02	0.6000E-02	0.8680E 07	3E
-25	0.4980E-02	0.5480E-02	0.8750E 07	3D

GRAPHITE EPOXY VIBRATION DATA

TEMP	PERIOD	DAMPING RATIO	STORAGE MODULUS	SPEC
-25	0.4980E-02	0.5550E-02	0.8740E 07	3B
-25	0.4690E-02	0.5420E-02	0.9070E 07	3C
-25	0.3490E-02	0.6220E-02	0.8630E 07	1C
-25	0.3460E-02	0.6950E-02	0.8790E 07	1B
-25	0.3400E-02	0.5460E-02	0.9130E 07	1E
-25	0.3360E-02	0.6110E-02	0.9320E 07	1D
-25	0.3230E-02	0.6030E-02	0.9770E 07	1A
-25	0.2270E-02	0.5000E-02	0.8300E 07	2C
-25	0.2240E-02	0.4520E-02	0.8510E 07	2B
-25	0.2230E-02	0.4450E-02	0.8600E 07	2A
-25	0.2180E-02	0.5780E-02	0.9020E 07	2D
-25	0.2180E-02	0.4560E-02	0.8980E 07	2F
-25	0.1790E-02	0.4980E-02	0.8650E 07	3B
-25	0.1790E-02	0.6430E-02	0.8680E 07	3F
-25	0.1790E-02	0.5030E-02	0.8590E 07	3A
-25	0.1780E-02	0.4990E-02	0.8780E 07	3D
-25	0.1750E-02	0.4960E-02	0.9020E 07	3C
-25	0.5620E-03	0.4500E-02	0.8480E 07	1C
-25	0.5560E-03	0.4640E-02	0.8680E 07	1B
-25	0.5480E-03	0.4390E-02	0.8920E 07	1E
-25	0.5370E-03	0.4300E-02	0.9280E 07	1D
-25	0.5290E-03	0.5290E-02	0.9580E 07	1A
-25	0.3107E-03	0.6000E-02	0.9440E 07	8B
-25	0.3082E-03	0.6500E-02	0.9600E 07	8A
-25	0.3067E-03	0.5400E-02	0.9690E 07	8D
-25	0.3045E-03	0.7300E-02	0.9830E 07	8C
-25	0.3040E-03	0.5600E-02	0.9860E 07	8E
-25	0.2404E-03	0.1620E-01	0.8870E 07	7E
-25	0.2366E-03	0.1290E-01	0.9010E 07	7D
-25	0.2361E-03	0.1640E-01	0.9170E 07	7B
-25	0.2344E-03	0.1580E-01	0.9340E 07	7C
-25	0.2340E-03	0.1690E-01	0.9360E 07	7A
-25	0.1612E-03	0.8000E-02	0.8770E 07	6A
-25	0.1609E-03	0.9700E-02	0.8800E 07	6E
-25	0.1608E-03	0.6200E-02	0.8840E 07	6B
-25	0.1583E-03	0.7100E-02	0.9090E 07	6D
-25	0.1531E-03	0.9100E-02	0.9120E 07	6C
-25	0.1039E-03	0.5200E-02	0.9370E 07	8B
-25	0.1030E-03	0.5900E-02	0.9540E 07	8A
-25	0.1024E-03	0.5400E-02	0.9660E 07	8C
-25	0.1020E-03	0.5100E-02	0.9730E 07	8D
-25	0.1017E-03	0.5600E-02	0.9780E 07	8E
-25	0.8010E-04	0.5200E-02	0.8880E 07	5A
-25	0.7980E-04	0.1960E-01	0.8950E 07	5D
-25	0.7920E-04	0.1630E-01	0.9070E 07	5E
-25	0.7710E-04	0.2850E-01	0.9590E 07	5C

GRAPHITE EPOXY VIBRATION DATA

TEMP	PERIOD	DAMPING RATIO	STORAGE MODULUS	SPEC
-25	0.7690E-04	0.9600E-02	0.9630E 07	5B
0	0.5590E-01	0.4580E-01	0.8630E 07	4D
0	0.5560E-01	0.3830E-01	0.8730E 07	4A
0	0.5490E-01	0.4060E-01	0.8930E 07	4B
0	0.5460E-01	0.4090E-01	0.9020E 07	4E
0	0.5340E-01	0.4220E-01	0.9450E 07	4C
0	0.3160E-01	0.3410E-01	0.8550E 07	3B
0	0.3160E-01	0.3420E-01	0.8510E 07	3A
0	0.3150E-01	0.3000E-01	0.8610E 07	3D
0	0.3120E-01	0.3570E-01	0.8770E 07	3E
0	0.3060E-01	0.3430E-01	0.9100E 07	3C
0	0.1570E-01	0.1570E-01	0.8250E 07	2C
0	0.1400E-01	0.1610E-01	0.8570E 07	2B
0	0.1390E-01	0.1740E-01	0.8670E 07	2A
0	0.1380E-01	0.1550E-01	0.8820E 07	2E
0	0.1370E-01	0.1580E-01	0.8970E 07	2D
0	0.8950E-02	0.7340E-02	0.8560E 07	4D
0	0.8880E-02	0.7100E-02	0.8700E 07	4A
0	0.8770E-02	0.7240E-02	0.8910E 07	4B
0	0.8650E-02	0.6400E-02	0.9170E 07	4E
0	0.8580E-02	0.7120E-02	0.9320E 07	4C
0	0.5020E-02	0.3990E-02	0.8610E 07	3A
0	0.5000E-02	0.6000E-02	0.8680E 07	3E
0	0.4980E-02	0.4980E-02	0.8740E 07	3D
0	0.4970E-02	0.6010E-02	0.8780E 07	3B
0	0.4900E-02	0.5420E-02	0.9050E 07	3C
0	0.3500E-02	0.6300E-02	0.8600E 07	1C
0	0.3480E-02	0.4960E-02	0.8710E 07	1B
0	0.3400E-02	0.6800E-02	0.9100E 07	1F
0	0.3360E-02	0.5870E-02	0.9330E 07	1D
0	0.3290E-02	0.6010E-02	0.9710E 07	1A
0	0.2280E-02	0.4150E-02	0.8280E 07	2C
0	0.2240E-02	0.4930E-02	0.8520E 07	2B
0	0.2240E-02	0.4050E-02	0.8580E 07	2A
0	0.2190E-02	0.5430E-02	0.8950E 07	2D
0	0.2190E-02	0.4530E-02	0.8930E 07	2E
0	0.1790E-02	0.6470E-02	0.8670E 07	3B
0	0.1790E-02	0.5050E-02	0.8610E 07	3A
0	0.1780E-02	0.5760E-02	0.8670E 07	3E
0	0.1770E-02	0.5010E-02	0.8790E 07	3D
0	0.1750E-02	0.4240E-02	0.9010E 07	3C
0	0.5630E-03	0.5060E-02	0.8460E 07	1C
0	0.5570E-03	0.5040E-02	0.8630E 07	1B
0	0.5500E-03	0.3850E-02	0.8860E 07	1E
0	0.5390E-03	0.4850E-02	0.9230E 07	1D
0	0.5300E-03	0.4770E-02	0.9530E 07	1A

GRAPHITE EPOXY VIBRATION DATA

TEMP	PERIOD	DAMPING RATIO	STORAGE MODULUS	SPEC
0	0.3127E-03	0.6300E-02	0.9320E 07	8B
0	0.3094E-03	0.6200E-02	0.9520E 07	8A
0	0.3062E-03	0.7900E-02	0.9720E 07	8C
0	0.3054E-03	0.6200E-02	0.9770E 07	8E
0	0.2989E-03	0.7700E-02	0.9610E 07	8D
0	0.2405E-03	0.1620E-01	0.8870E 07	7E
0	0.2386E-03	0.1290E-01	0.9010E 07	7D
0	0.2366E-03	0.1890E-01	0.9160E 07	7B
0	0.2363E-03	0.1380E-01	0.9180E 07	7A
0	0.2358E-03	0.1550E-01	0.9220E 07	7C
0	0.1621E-03	0.8700E-02	0.8670E 07	6A
0	0.1616E-03	0.1170E-01	0.8720E 07	6E
0	0.1611E-03	0.6500E-02	0.8790E 07	6B
0	0.1590E-03	0.8000E-02	0.9020E 07	6D
0	0.1587E-03	0.9200E-02	0.9050E 07	6C
0	0.1043E-03	0.6100E-02	0.9300E 07	8B
0	0.1034E-03	0.6200E-02	0.9460E 07	8A
0	0.1026E-03	0.5500E-02	0.9610E 07	8C
0	0.1021E-03	0.5100E-02	0.9700E 07	8D
0	0.1019E-03	0.6100E-02	0.9740E 07	8E
0	0.8050E-04	0.5200E-02	0.8800E 07	5A
0	0.8000E-04	0.1800E-01	0.8900E 07	5D
0	0.7970E-04	0.1560E-01	0.8980E 07	5E
0	0.7730E-04	0.2900E-01	0.9540F 07	5C
0	0.7720E-04	0.8500E-02	0.9560E 07	5B
80	0.5560E-01	0.3060E-01	0.8730E 07	4D
80	0.5510E-01	0.2760E-01	0.8860E 07	4A
80	0.5430E-01	0.2660E-01	0.9120E 07	4B
80	0.5410E-01	0.2610E-01	0.9190E 07	4E
80	0.5320E-01	0.3240E-01	0.9520E 07	4C
80	0.3140E-01	0.3520E-01	0.8620E 07	3E
80	0.3140E-01	0.2450E-01	0.8620E 07	3A
80	0.3140E-01	0.2030E-01	0.8660E 07	3D
80	0.3130E-01	0.2340E-01	0.8680E 07	3B
80	0.3050E-01	0.2360E-01	0.9150E 07	3C
80	0.1430E-01	0.1220E-01	0.8190E 07	2C
80	0.1390E-01	0.1270E-01	0.8690E 07	2B
80	0.1380E-01	0.1250E-01	0.8790F 07	2A
80	0.1370E-01	0.1040E-01	0.9010E 07	2D
80	0.1370E-01	0.1180E-01	0.8980E 07	2E
80	0.8890E-02	0.6220E-02	0.8680E 07	4A
80	0.8880E-02	0.6080E-02	0.8700E 07	4D
80	0.8800E-02	0.6010E-02	0.8870E 07	4B
80	0.8700E-02	0.5700E-02	0.9070E 07	4E
80	0.8580E-02	0.6080E-02	0.9310F 07	4C
80	0.5030E-02	0.3750E-02	0.8570E 07	3A

GRAPHITE EPOXY VIBRATION DATA

TEMP	PERIOD	DAMPING RATIO	STORAGE MODULUS	SPEC
80	0.4990E-02	0.5020E-02	0.8720E 07	3E
80	0.4980E-02	0.5470E-02	0.8770E 07	3B
80	0.4970E-02	0.4470E-02	0.8790E 07	3D
80	0.4900E-02	0.3920E-02	0.9050E 07	3C
80	0.3490E-02	0.4210E-02	0.8620E 07	1C
80	0.3490E-02	0.3520E-02	0.8660E 07	1B
80	0.3380E-02	0.5410E-02	0.9220E 07	1E
80	0.3360E-02	0.4730E-02	0.9310E 07	1D
80	0.3300E-02	0.3340E-02	0.9640E 07	1A
80	0.2270E-02	0.4150E-02	0.8280E 07	2C
80	0.2240E-02	0.4010E-02	0.8520E 07	2B
80	0.2230E-02	0.3600E-02	0.8590E 07	2A
80	0.2190E-02	0.3970E-02	0.8980E 07	2E
80	0.2180E-02	0.4850E-02	0.8990E 07	2D
80	0.1800E-02	0.5080E-02	0.8590E 07	3A
80	0.1790E-02	0.5060E-02	0.8670E 07	3B
80	0.1780E-02	0.5010E-02	0.8720E 07	3E
80	0.1770E-02	0.4300E-02	0.8820E 07	3D
80	0.1750E-02	0.4230E-02	0.9040E 07	3C
80	0.5620E-03	0.3950E-02	0.8470E 07	1C
80	0.5580E-03	0.4590E-02	0.8610E 07	1B
80	0.5480E-03	0.3850E-02	0.8910E 07	1E
80	0.5380E-03	0.4310E-02	0.9250E 07	1D
80	0.5300E-03	0.3710E-02	0.9540E 07	1A
80	0.3148E-03	0.6300E-02	0.9200E 07	8B
80	0.3113E-03	0.6900E-02	0.9410E 07	8A
80	0.3094E-03	0.4900E-02	0.9520E 07	8D
80	0.3080E-03	0.7700E-02	0.9610E 07	8C
80	0.3067E-03	0.6200E-02	0.9690E 07	8E
80	0.2407E-03	0.1080E-01	0.8850E 07	7D
80	0.2384E-03	0.1930E-01	0.9020E 07	7E
80	0.2373E-03	0.1500E-01	0.9110E 07	7A
80	0.2366E-03	0.1810E-01	0.9160E 07	7B
80	0.2366E-03	0.1700E-01	0.9160E 07	7C
80	0.1630E-03	0.8100E-02	0.8580E 07	6E
80	0.1628E-03	0.7300E-02	0.8600E 07	6A
80	0.1528E-03	0.7400E-02	0.8600E 07	6B
80	0.1596E-03	0.1240E-01	0.8950E 07	6D
80	0.1586E-03	0.9000E-02	0.9060E 07	6C
80	0.1052E-03	0.6300E-02	0.9150E 07	8B
80	0.1045E-03	0.1100E-01	0.9270E 07	8A
80	0.1034E-03	0.5500E-02	0.9460E 07	8C
80	0.1030E-03	0.5200E-02	0.9540E 07	8D
80	0.1026E-03	0.5700E-02	0.9610E 07	8E
80	0.8120E-04	0.5700E-02	0.8640E 07	5A
80	0.8000E-04	0.2380E-01	0.8770E 07	5D

GRAPHITE EPOXY VIBRATION DATA

TEMP	PERIOD	DAMPING RATIO	STORAGE MODULUS	SPEC
80	0.8020E-04	0.1620E-01	0.8870E 07	5E
80	0.7760E-04	0.1080E-01	0.9470E 07	5B
80	0.7760E-04	0.2560E-01	0.9460E 07	5C
200	0.5580E-01	0.2570E-01	0.8650E 07	4D
200	0.5560E-01	0.2440E-01	0.8730E 07	4A
200	0.5460E-01	0.2350E-01	0.9020E 07	4B
200	0.5430E-01	0.2280E-01	0.9120E 07	4E
200	0.5290E-01	0.2330E-01	0.9620E 07	4C
200	0.3150E-01	0.1890E-01	0.8600E 07	3A
200	0.3140E-01	0.1820E-01	0.8620E 07	3B
200	0.3130E-01	0.1690E-01	0.8680E 07	3D
200	0.3110E-01	0.2050E-01	0.8790E 07	3E
200	0.3060E-01	0.2430E-01	0.9070E 07	3C
200	0.1450E-01	0.1030E-01	0.8030E 07	2C
200	0.1400E-01	0.1070E-01	0.8620E 07	2B
200	0.1400E-01	0.1140E-01	0.8580E 07	2A
200	0.1380E-01	0.1020E-01	0.8850E 07	2D
200	0.1370E-01	0.1190E-01	0.8940E 07	2E
200	0.8940E-02	0.5810E-02	0.8590E 07	4D
200	0.8930E-02	0.6250E-02	0.8600E 07	4A
200	0.8830E-02	0.5910E-02	0.8790E 07	4B
200	0.8700E-02	0.5200E-02	0.9050E 07	4E
200	0.8600E-02	0.5670E-02	0.9280E 07	4C
200	0.5050E-02	0.3540E-02	0.8510E 07	3A
200	0.5020E-02	0.4550E-02	0.8620E 07	3E
200	0.5000E-02	0.5000E-02	0.8660E 07	3B
200	0.4990E-02	0.4020E-02	0.8710E 07	3D
200	0.4920E-02	0.3940E-02	0.8960E 07	3C
200	0.3510E-02	0.3530E-02	0.8540E 07	1C
200	0.3500E-02	0.3500E-02	0.8610E 07	1B
200	0.3390E-02	0.4840E-02	0.9150E 07	1E
200	0.3380E-02	0.3400E-02	0.9210E 07	1D
200	0.3290E-02	0.4730E-02	0.9700E 07	1A
200	0.2280E-02	0.3670E-02	0.8220E 07	2C
200	0.2250E-02	0.3620E-02	0.8440E 07	2B
200	0.2240E-02	0.3590E-02	0.8550E 07	2A
200	0.2200E-02	0.3610E-02	0.8890E 07	2D
200	0.2190E-02	0.3380E-02	0.8930E 07	2E
200	0.1800E-02	0.4380E-02	0.8520E 07	3A
200	0.1800E-02	0.3590E-02	0.8590E 07	3E
200	0.1790E-02	0.4340E-02	0.8680E 07	3D
200	0.1790E-02	0.3600E-02	0.8600E 07	3B
200	0.1760E-02	0.3500E-02	0.8970E 07	3C
200	0.5680E-03	0.2840E-02	0.8320E 07	1C
200	0.5610E-03	0.3360E-02	0.8610E 07	1B
200	0.5520E-03	0.3320E-02	0.8810E 07	1E

GRAPHITE EPOXY VIBRATION DATA

TEMP	PERIOD	DAMPING RATIO	STORAGE MODULUS	SPEC
200	0.5410E-03	0.3220E-02	0.9140E 07	1D
200	0.5330E-03	0.4270E-02	0.9420E 07	1A
200	0.3215E-03	0.9700E-02	0.8820E 07	8B
200	0.3192E-03	0.1790E-01	0.8950E 07	8A
200	0.3145E-03	0.5000E-02	0.9220E 07	8D
200	0.3131E-03	0.9400E-02	0.9300E 07	8C
200	0.3125E-03	0.7900E-02	0.9340E 07	8E
200	0.2447E-03	0.1370E-01	0.8570E 07	7D
200	0.2437E-03	0.2060E-01	0.8640E 07	7E
200	0.2419E-03	0.1740E-01	0.8760E 07	7A
200	0.2414E-03	0.1780E-01	0.8800E 07	7B
200	0.2410E-03	0.1520E-01	0.8830E 07	7C
200	0.1668E-03	0.1050E-01	0.8200E 07	6A
200	0.1663E-03	0.9400E-02	0.8250E 07	6B
200	0.1663E-03	0.8200E-02	0.8340E 07	6E
200	0.1621E-03	0.1230E-01	0.8670E 07	6C
200	0.1620E-03	0.1310E-01	0.8680E 07	6D
200	0.1072E-03	0.8600E-02	0.8810E 07	8B
200	0.1070E-03	0.2040E-01	0.8840E 07	8A
200	0.1058E-03	0.1320E-01	0.9040E 07	8C
200	0.1046E-03	0.8400E-02	0.9290E 07	8E
200	0.1044E-03	0.4900E-02	0.9290E 07	8D
200	0.8350E-04	0.1750E-01	0.8170E 07	5A
200	0.8230E-04	0.1900E-01	0.8420E 07	5D
200	0.8100E-04	0.1210E-01	0.8690E 07	5E
200	0.7850E-04	0.4300E-02	0.9230E 07	5B
200	0.7640E-04	0.1840E-01	0.9260E 07	5C
300	0.5580E-01	0.2450E-01	0.8660E 07	4D
300	0.5560E-01	0.2390E-01	0.8730E 07	4A
300	0.5470E-01	0.2190E-01	0.9010E 07	4B
300	0.5430E-01	0.2220E-01	0.9120E 07	4E
300	0.5320E-01	0.2290E-01	0.9530E 07	4C
300	0.3150E-01	0.1830E-01	0.8560E 07	3A
300	0.3140E-01	0.1890E-01	0.8620E 07	3E
300	0.3140E-01	0.1820E-01	0.8620E 07	3B
300	0.3110E-01	0.1790E-01	0.8800E 07	3D
300	0.3090E-01	0.1840E-01	0.8910E 07	3C
300	0.1440E-01	0.9330E-02	0.8170E 07	2C
300	0.1400E-01	0.9620E-02	0.8550E 07	2B
300	0.1390E-01	0.9720E-02	0.8730E 07	2A
300	0.1370E-01	0.9390E-02	0.8990E 07	2D
300	0.1370E-01	0.1060E-01	0.9010E 07	2E
300	0.8970E-02	0.5450E-02	0.8520E 07	4A
300	0.8940E-02	0.5370E-02	0.8570E 07	4D
300	0.8830E-02	0.5300E-02	0.8800E 07	4B
300	0.8700E-02	0.5200E-02	0.9070E 07	4E

GRAPHITE EPOXY VIBRATION DATA

TEMP	PERIOD	DAMPING RATIO	STORAGE MODULUS	SPEC
300	0.8630E-02	0.5690E-02	0.9210E 07	4C
300	0.5050E-02	0.6060E-02	0.8500E 07	3A
300	0.5030E-02	0.4520E-02	0.8590E 07	3B
300	0.5030E-02	0.3520E-02	0.8590E 07	3F
300	0.5010E-02	0.4540E-02	0.8640E 07	3D
300	0.4890E-02	0.3380E-02	0.9060E 07	3C
300	0.3520E-02	0.3520E-02	0.8490E 07	1C
300	0.3500E-02	0.2110E-02	0.8570E 07	1B
300	0.3400E-02	0.3830E-02	0.9090E 07	1E
300	0.3390E-02	0.3550E-02	0.9160E 07	1D
300	0.3300E-02	0.4610E-02	0.9690E 07	1A
300	0.2290E-02	0.5960E-02	0.8150E 07	2C
300	0.2260E-02	0.3610E-02	0.8410E 07	2B
300	0.2260E-02	0.5430E-02	0.8410E 07	2A
300	0.2190E-02	0.3590E-02	0.8910E 07	2D
300	0.2190E-02	0.5180E-02	0.8900E 07	2E
300	0.1810E-02	0.3610E-02	0.8500E 07	3B
300	0.1800E-02	0.4360E-02	0.8530E 07	3A
300	0.1790E-02	0.5010E-02	0.8620E 07	3E
300	0.1780E-02	0.4990E-02	0.8870E 07	3D
300	0.1760E-02	0.4270E-02	0.8960E 07	3C
300	0.5680E-03	0.2840E-02	0.8310E 07	1C
300	0.5610E-03	0.3940E-02	0.8520E 07	1B
300	0.5530E-03	0.2770E-02	0.8770E 07	1E
300	0.5430E-03	0.2720E-02	0.9080E 07	1D
300	0.5340E-03	0.3200E-02	0.9410E 07	1A
300	0.3237E-03	0.1940E-01	0.8700E 07	8B
300	0.3235E-03	0.3170E-01	0.8720E 07	8A
300	0.3151E-03	0.1900E-01	0.9180E 07	8C
300	0.3141E-03	0.4400E-02	0.9240E 07	8D
300	0.2461E-03	0.9300E-02	0.8470E 07	7D
300	0.2453E-03	0.1660E-01	0.8520E 07	7E
300	0.2427E-03	0.1350E-01	0.8710E 07	7C
300	0.2421E-03	0.1700E-01	0.8750E 07	7A
300	0.2420E-03	0.1740E-01	0.8760E 07	7B
300	0.1696E-03	0.1530E-01	0.7930E 07	6A
300	0.1672E-03	0.7500E-02	0.8160E 07	6B
300	0.1666E-03	0.1200E-01	0.8220E 07	6E
300	0.1644E-03	0.1260E-01	0.8430E 07	6C
300	0.1640E-03	0.1250E-01	0.8480E 07	6D
300	0.1078E-03	0.1080E-01	0.8700E 07	8B
300	0.1074E-03	0.2320E-01	0.8770E 07	8A
300	0.1069E-03	0.1820E-01	0.8860E 07	8C
300	0.1047E-03	0.3200E-02	0.9270E 07	8D
300	0.8390E-04	0.1760E-01	0.8090E 07	5A
300	0.8300E-04	0.2080E-01	0.8280E 07	5D

GRAPHITE EPOXY VIBRATION DATA

TEMP	PERIOD	DAMPING RATIO	STORAGE MODULUS	SPEC
300	0.8130E-04	0.1680E-01	0.8610E 07	5E
300	0.7680E-04	0.3900E-02	0.9190E 07	5B

IX. REFERENCES

1. Kaminski, B. E.; Lemon, G. H.; and McKogue, E. L.: Development of Engineering Data for Advanced Composite Materials. Convair Aerospace Division of General Dynamics, Fort Worth Operation. Technical Report AFML-TR-70-108, Vol. 1. October, 1972.

2. Life Assurance of Composite Structures, Second Quarterly Progress Report. Convair Aerospace Division of General Dynamics, Fort Worth Operation. December 15, 1973.

3. Browning, C. E.: The Effects of Moisture on the Properties of High Performance Structural Resins and Composites. 28th Annual Technical Conference, Reinforced Plastics/Composites Institute, The Society of Plastics Industry, Inc. 1973.

4. Pritchard, G; and Taneja, N.: Water Damage in Polyester Glass Laminates, Composites. July, 1973.

5. Development of Engineering Data on the Mechanical and Physical Properties of Advanced Composite Materials. IIT Research Institute. September, 1972.

6. Tsai, S. W.; Halpin, J. C.; Pagano, N. J.: Composite Materials Workshop. Technomic, Stamford, Connecticut, pp. 87-152. 1968.

7. Heller, R. A.; Swift, G. W.; Stinchcomb, W. W.; Thakker, A. B.; and Liu, J. C.: Time and Temperature Dependence of Boron-Epoxy and Graphite-Epoxy Laminates. Virginia Polytechnic Institute and State University, Technical Report AFML-TR-73-261. November, 1973.

8. Snowden, J. C.: Vibration and Shock in Damped Mechanical Systems. Wiley, New York, p. 271. 1968.

9. Myers, R. H.: Response Surface Methodology. Allyn and Bacon, Boston, pp. 26-29. 1971.

10. Barr, A. J.; and Goodnight, J. H.: SAS, A User's Guide to the Statistical Analysis System. North Carolina State University, Raleigh, North Carolina. 1972.

11. Hamburg, Morris: Statistical Analysis for Decision Making. Harcourt, Brace, and World, Inc., New York, p. 523. 1970.

12. Heller, R. A.; Thakker, A. B.; and Arthur, C. E.: Temperature Dependence of the Complex Modulus for Fiber Reinforced Materials. Virginia Polytechnic Institute and State University, Presented at the Composite Reliability Conference, Las Vegas, Nevada. April, 1974.